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Gulf Menhaden, *Brevoortia patronus*, Purse Seine Fishery: Catch, Fishing Activity, and Age and Size Composition, 1964-73

William R. Nicholson

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Juanita M. Kreps, Secretary
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Richard A. Frank, Administrator
National Marine Fisheries Service

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Gulf Menhaden, *Brevoortia patronus*, Purse Seine Fishery: Catch, Fishing Activity, and Age and Size Composition, 1964-73

WILLIAM R. NICHOLSON[1]

ABSTRACT

The menhaden purse seine fishery in the Gulf of Mexico, primarily for Gulf menhaden, *Brevoortia patronus*, extends from about early April to early October. From 1964 to 1973 the catch fluctuated between 317,000 and 728,000 t and the number of vessels ranged from 65 to 82. Larger and faster refrigerated vessels replaced most of the smaller nonrefrigerated vessels and modern methods of fishing were adopted. Population levels were high and there were no large fluctuations in year class abundance. Age-1 and -2 fish supplied from 95 to 99% of the catch by weight. Over 97% of the fish were between 120 and 225 mm fork length. The mean age and size generally were slightly greater in the center of the fishery (central and eastern Louisiana) than in the eastern (Mississippi) and western areas (western Louisiana and Texas). Mean age decreased as the season progressed.

INTRODUCTION

he menhaden purse seine fishery in the Gulf of
, dating prior to 1900, underwent a rapid expan-
ter World War II. New plants for processing meal
oil were built and larger and more modern vessels
e added to the fleet. By 1964 the annual catch had
410,000 t, a 10-fold increase over the 1946 catch.
ough three species of menhaden inhabit the area,
y the Gulf menhaden, *Brevoortia patronus*, is impor-
t to the fishery. Yellowfin menhaden, *B. smithi*, oc-
ast of the Mississippi delta, and finescale men-
B. gunteri, west of the delta (Christmas and
nter 1960). These two species together, however,
ly supply, on the basis of numbers observed in
s or found in catch samples, less than 1% of the
nhaden processed.

ecause of general concern that the resource would be
hed and that catches would undergo a decline
to that of Atlantic menhaden, *B. tyrannus*, an in-
tigation was begun in 1964 by the National Marine
heries Service and centered at the Beaufort, N.C.,
tory. Many of the procedures and techniques
ped for collecting and compiling information on
Atlantic menhaden fishery were followed. Catches of
ividual vessels dating from 1945 were compiled from
ential company records, and information on im-
ents in fishing methods, such as the use of spotter
nes, fish pumps, and power blocks, were collected. A
atic sampling of catches for age, size, and sex was
in 1964 and still continues.

he purpose of this paper is to document changes that
e occurred in the fishery, update records of landings, describe methods of sampling the catch and estimating the number of fish landed at each age, and discuss differences or similarities in age and size composition of catches throughout the fishery. Some preliminary data on catches, number of vessels and airplanes, and age composition of catches have been published in annual reports of the Beaufort Laboratory and by Chapoton (1972). Previous reports on age composition, however, were inaccurate, particularly for the years 1964-69, because a majority of fish had been over-aged during preliminary aging procedures. Subsequent reading showed a greater number of age-1 fish, fewer fish over age-2, and none over age-3.

THE FISHERY

Although a menhaden fishery has existed along the Gulf coast since the late 1800's, records of catches, the location and number of plants, and the number and types of vessels before 1946 are fragmentary. One plant is known to have operated in Texas from around the turn of the century until at least 1923. Another operated intermittently in the vicinity of Port St. Joe and Apalachicola, Fla., from at least 1918 until 1961. Another operated in the Pascagoula, Miss., area from sometime in the 1930's until 1959.

The modern purse seine fishery began after World War II as the world demand for fish meal and oil increased. Fishing usually begins in April and ends in early October. The first plant in Louisiana opened in 1946. In the next few years additional plants were built in Mississippi, Louisiana, and Texas (Fig. 1). Since 1950 the number of plants operating each year has fluctuated between 9 and 13 (Table 1), with some plants being closed or destroyed and new ones being built. The general trend has been toward larger and more efficient plants.

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outheast Fisheries Center Beaufort Laboratory, National Marine
eries, NOAA, Beaufort, NC 28516.

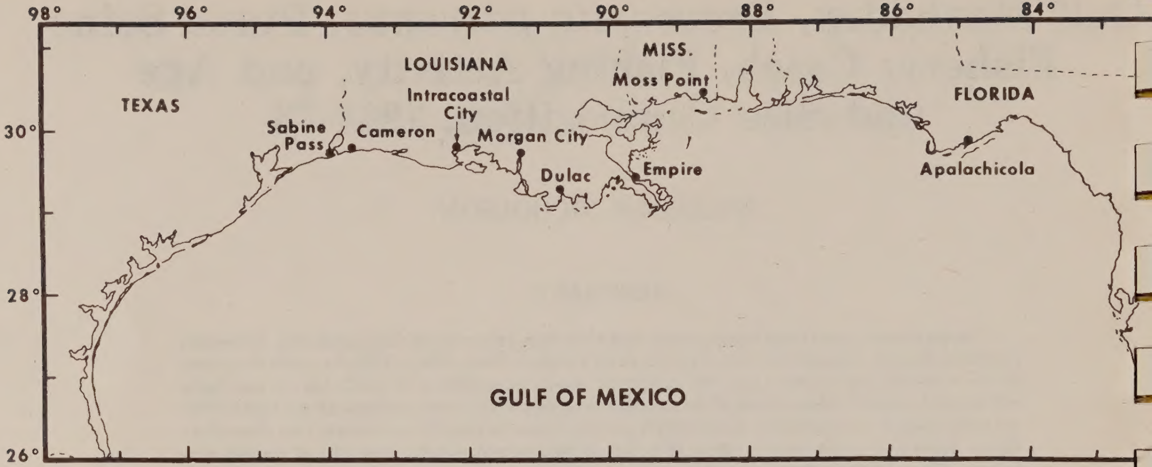

Figure 1.—Location of reduction plants for the Gulf menhaden fishery in the Gulf of Mexico.

Table 1.—Numbers of operating plants, airplanes, vessels by size, and vessels with fish pumps, power blocks, and refrigeration, Gulf menhaden fishery, 1945-73.

			No. of vessels[1]				No. of vessels with		
Years	No. of plants operating	No. of air-planes	Under 75 net tons	76-200 net tons	Over 200 net tons	Total	Fish pumps	Power blocks	Re-friger-ation
1945	2	0	10	0	0	10	0	0	0
1946	3	0	13	1	0	14	0	0	0
1947	4	0	21	9	0	30	0	0	0
1948	5	0	27	12	0	39	0	0	0
1949	7	1	36	17	0	53	0	0	0
1950	10	3	42	23	0	65	0	0	0
1951	10	4	42	26	0	68	6	0	0
1952	10	4	41	23	0	64	7	0	0
1953	10	5	46	24	0	70	12	0	0
1954	9	7	40	32	0	72	39	0	0
1955	9	8	39	31	2	72	43	0	0
1956	10	12	38	39	4	81	63	0	2
1957	10	15	32	35	6	73	72	4	9
1958	10	15	20	48	9	77	69	7	14
1959	11	17	18	44	11	73	66	16	23
1960	10	19	12	52	11	75	71	21	29
1961	10	19	6	52	11	69	66	21	32
1962	12	23	6	54	14	74	74	43	35
1963	11	25	5	53	15	73	73	56	36
1964	11	24	5	53	18	76	76	64	40
1965	13	27	4	48	30	82	82	79	57
1966	13	29	1	42	37	80	80	80	59
1967	13	31	1	32	43	76	76	76	70
1968	12	33	2	26	41	69	69	69	65
1969	12	33	2	27	43	72	72	72	68
1970	13	34	2	26	45	73	73	73	70
1971	13	35	1	29	52	82	82	82	77
1972	11	33	0	22	53	75	75	75	75
1973	10	31	0	14	51	65	65	65	65

[1] Number of vessels that landed fish 9 or more weeks.

Distribution of Fishing

From 1964 to 1969 logbooks and maps were placed aboard vessels and the captain or pilot was asked to record, among other things, the location of each purse seine set. Squares on the maps, formed by even degrees of latitude and longitude, were divided by 10 minu tervals into 36 subareas, identified by a letter (A and a number (1 to 6). The location of a given set co be referenced within a 100 mi^2 subarea, identifi latitude, longitude, and subarea (for example 29-84 Although all vessels did not keep logs and some kep partial records, the locations of over 48,000 sets were ded for the 6-yr period.

show the relative distribution of fishing activity, particularly in reference to distance from shore, I organized the data by degrees of longitude to show the per- ge of sets made less than 10, 20, 30, and 40 mi from (Table 2). Since longitude 89 is divided by the Mississippi Delta, I treated the data from east of the delta (89a) and west of the delta (89b) separately. West e Mississippi delta (longitudes 89b-94), 44 to 93% of ets were less than 10 mi from shore, 90 to 98% less than 20 mi, and 99 to 100% less than 30 mi. East of the delta (longitudes 84-89a), 100% of the sets were made less 10 mi from shore.

effect, the fishing area west of the delta is restricted to a narrower band adjacent to shore than is indicated by data. Because the shoreline usually passes through reas rather than along their boundaries, the actual distances from shore are considerably less than the maximum. Therefore, a majority of the sets are in reality less the maximum possible distance. Probably 85 to are made within 15 mi of shore. Undoubtedly many reported in subareas more than 20 mi were due to errors in recording.

hes

Records of annual catches were compiled from con- tial company sources of individual vessel landings ears 1945-73 (Table 3). In a few cases where plant records were missing (one plant in Mississippi 1949-50, one plant in Louisiana 1954-55, and one plant in Texas -51), I estimated catches by multiplying the mean of similar vessels at nearby plants by the number of vessels that normally fished at plants whose records were missing. For Florida in 1946-47 and Mississippi in where only one plant operated, I was unable, however, to make any estimates and no published records were available.

blished records (Anonymous 1918-38, 1939-44) prior 45, although fragmentary and incomplete, suggest annual landings from 1918 to 1944 of about 2,000 to 12,000 t, all in Florida, Mississippi, or Texas. There was lit- ncrease until 1948, when the catch was 103,000 t, ly as a result of new plants being built in Mississippi, Louisiana, and Texas. It had increased to 481,000 t by 1962 and thereafter fluctuated between 317,000 and 728,000 t. More vessels, larger and more efficient vessels, and improved fishing technology were primarily responsible for increased catches after 1947.

Table 3.—Purse seine catch of Gulf menhaden, in thousands of metric tons, by State, 1945-73.

Year	Florida	Mississippi	Louisiana	Texas	Total
1945	3.2	26.0	0.0	0.0	29.2
1946	[1]	[1]	8.9	0.0	[1]
1947	[1]	10.1	24.0	0.0	[1]
1948	15.4	34.8	40.0	12.7	102.9
1949	11.2	30.1	75.2	19.0	135.5
1950	0.6	31.1	94.3	21.2	147.2
1951	1.5	43.4	96.7	13.2	154.8
1952	4.8	70.7	129.2	24.0	228.7
1953	2.0	22.1	142.1	30.3	196.5
1954	0.0	36.0	121.8	23.4	181.2
1955	0.9	56.0	135.1	23.0	215.0
1956	0.0	70.3	144.6	29.9	244.8
1957	0.0	59.3	74.5	26.1	159.9
1958	4.6	56.1	109.5	31.3	201.5
1959	8.2	79.7	191.5	55.9	335.3
1960	2.8	99.1	213.2	65.6	380.7
1961	1.9	136.7	260.2	60.7	459.5
1962	0.0	119.5	314.1	47.1	480.7
1963	0.0	113.6	288.4	35.8	437.8
1964	0.0	107.8	271.4	30.2	409.4
1965	0.0	126.4	308.6	28.1	463.1
1966	3.1	86.4	252.0	17.6	359.1
1967	0.0	75.5	231.4	10.4	317.3
1968	0.3	67.8	282.2	23.2	373.5
1969	0.0	102.2	388.3	33.2	523.7
1970	0.0	93.4	435.2	19.5	548.1
1971	0.0	138.8	560.9	28.5	728.2
1972	0.0	80.8	420.9	0.0	501.7
1973	0.0	80.4	405.7	0.0	486.1

[1] Records not available.

Size and Number of Vessels

The number of vessels increased rapidly from 1945 to 1950, and then more slowly, reached a peak of 82 in 1965, and thereafter fluctuated between 65 and 82 (Table 1). Because many vessels often made only a few landings each year in the early years of the fishery, I have excluded all vessels that fished less than 9 wk. Including them would have indicated greater changes in the composition of the fleet than actually occurred.

Table 2.—Distribution of purse seine sets for Gulf menhaden, by degrees of longitude and relative distance from shore, 1964-69. Longitudes 84-89a are east of the Mississippi delta, 89b-94 are west.

	Longitude (°W)									
Sets	94	93	92	91	90	89b	89a	88	87-86	85-84
Number	598	4,310	4,672	10,328	1,730	2,539	14,486	9,050	94	767
% 0 to 10 miles of shore	68	57	44	48	85	93	100	100	100	100
% 0 to 20 miles of shore	91	93	90	98	98	98	0	0	0	0
% 0 to 30 miles of shore	99	99	99	100	100	100	0	0	0	0

The shift to larger vessels of greater carrying capacity was the most striking change. Vessels less than 75 net tons constituted over 50% of the fleet until 1956. In the following years the number of vessels in this size class declined continually, dropping to 1 in 1966 and finally disappearing completely in 1972. The number of vessels between 75 and 200 net tons increased until 1960, remained fairly stable through 1964, and then declined steadily. By 1973 they composed only 22% of the fleet. Vessels over 200 net tons first appeared in 1955, increased gradually over the years, and by 1973 numbered 51, or 78% of the fleet. Most of the vessels in this size class after 1965 were greater than 300 net tons, and one was more than 400 net tons.

Improvements in Fishing Methods

Fish pumps, power blocks, refrigeration, nylon purse seines, aluminum purse boats, and airplane spotting were introduced in the Gulf menhaden fishery in the 1950's (Table 1). These techniques and equipment increased efficiency by reducing the time spent searching for fish, steaming to and from fishing grounds, and completing purse seine sets.

Fish pumps replaced the time-consuming method of brailing fish from the purse seine to the hold of the carrier vessel (Robas 1959), and first appeared on gulf coast vessels in 1951. By 1960 they were standard equipment on nearly all vessels.

A power block is a mechanical device that retrieves the net and concentrates the fish in it so they may be pumped or brailed aboard the carrier vessel. Its use reduces the average time required to concentrate the fish by about 6 min and the crew by 6 to 10 men (Schmidt 1959a, b), and permits a quick retrieval of the net if a school of fish is missed. Power blocks were introduced in the Gulf menhaden fishery in 1956. Although their did not spread rapidly, they were standard equipme over 80% of the vessels by 1964.

Refrigerated vessels are able to fish greater dist from their home ports and to spend up to a week on fishing grounds. Generally larger than nonrefrige vessels, they increased steadily in number after the troduction in 1957. Their use has been more extensiv the central and eastern Gulf regions, where vessels tra farther to the fishing grounds, than in the western

Aluminum purse boats can encircle a school o faster and can operate in rougher waters better t wooden or steel boats. They were first employed in 1 but their use spread slowly, and all vessels wer equipped with aluminum purse boats until about

Information was difficult to obtain on the use of ny seines by individual vessels. A few were reported to used them in 1956. The changeover was rapid in 195 1958, and by 1959 nearly all vessels were using th

The use of airplanes for locating schools of menha greatly reduced the amount of vessel searching tim was one of the more important improvements in fi methods. Spotter planes were introduced in the menhaden fishery in 1949 and rapidly increased in nu ber. Most plants chartered planes part time until 1955, but employed two to four planes full time by Initially, planes only guided vessels to large conc trations of fish, but in recent years pilots have used way radios to direct the purse boats in setting the

SAMPLING PROCEDURE

Catches of Gulf menhaden were sampled by sea employees who followed the procedures describe sampling catches of Atlantic menhaden (June Reintjes 1960). For each vessel sampled, fish were

Table 4.—Number of samples taken from Gulf menhaden catches by plant and location, 1964-73.

Plant location	No. of samples in year									
	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
Appalachicola, Fla.	[1]	[1]	4	[1]	0	[1]	[1]	[1]	[1]	[1]
Moss Pt., Miss.	76	98	33	25	29	53	43	19	58	[1]
	66	126	100	141	173	135	119	50	136	96
	56	88	53	89	53	71	66	56	102	102
Empire, La.	152	142	57	88	111	79	0	0	108	108
	18	25	63	71	70	75	0	0	153	166
Dulac, La.	1	2	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]
	0	5	4	4	15	0	7	4	[1]	[1]
	[1]	7	10	37	79	0	69	57	68	133
Morgan City, La.	111	126	90	103	73	147	56	41	49	133
Intracoastal City, La.	[1]	11	3	1	36	36	35	23	22	14
Cameron, La.	14	8	32	45	23	1	28	29	102	87
	118	112	152	76	105	157	69	57	68	94
	[1]	[1]	[1]	27	0	0	22	41	68	71
Sabine Pass, Tex.	4	16	26	1	6	3	4	9	[1]	[1]
Total	616	766	623	708	773	757	518	386	934	1,004

[1] Plant did not operate.

from the top of the catch, which came from the last set le by the vessel, measured (millimeters, fork length), weighed (grams), and sexed. Scales were taken for aging (Nicholson and Schaaf in press). In 1964, 1965, and 1971, samples of 20 fish (1 sample per boat) were taken y. From 1966 to 1970, three samples of 20 fish were taken. Beginning in 1972, three samples of 10 fish each were taken. The location of the last set made by the ves- was recorded to the nearest 10 minutes of latitude and itude.

All plants were not sampled equally. Usually, four samplers were employed and stationed at locations re they could cover two or more plants, arbitrarily grouped into ports. Locations were chosen so that plants throughout the entire range of the fishery could be sampled. The number of samples depended, in part, on duty station of the sampler and ranged from 0 to over [illegible] per plant and from 386 to 1,004 per year (Table 4).

AGE AND SIZE COMPOSITION

The number of fish landed at each plant was es- ted by dividing the total weight of fish landed week- y the mean weight of fish in the weekly samples, either from that plant or from several plants arbitrarily grouped together. The number of each age was es- ted by multiplying the total estimated number of fish by the percentage of each age in the samples. Weekly estimates were summed to obtain seasonal estimates. e fish landed at plants in the eastern and western of the fishery tended to be smaller and younger than fish landed at plants in the middle, I summarized the data by grouping together plants in the eastern area ssissippi and Florida), central area (Empire to Intra- tal City, La.), and western area (Cameron, La., and Sabine Pass, Tex.).

The total number of fish landed annually varied from 4.73 million in 1966 to 7,796.38 million in 1971 (Table ge-1 and -2 fish together supplied from 97 to 99% of the fish caught, and ages 0 and 3 supplied the remainder. -1 fish supplied from 59 to 92% of the estimated num- of fish caught annually, while age-2 fish supplied from 6 to 40%. These percentages are about the same, whether they are calculated from the estimated number sh caught or from the number of fish in the samples ble 6). The former method of calculating is more precise, since it corrects for differences in time and space between the ratio of weight of fish landed to number of in the samples.

here was remarkable little variation from year to year in the length range or mean length, either for individual ages or for all ages combined (Table 7). With few excep- s length ranged from about 115 to 215 mm. Mean an- lengths ranged from 147 to 165 mm for age-1 fish, 181 to 188 mm for age-2, 201 to 214 mm for fish over age- nd 153 to 172 mm for all ages combined.

eight also showed relatively little annual variation, ranging from about 20 to 250 g (Table 7). Means ranged from 65 to 101 g for age-1 fish, 122 to 148 g for age-2, 170 to 217 g for fish over age-2, and 74 to 117 g for all ages combined.

The contribution of each age group to the total weight of the catch was estimated by multiplying the number of fish caught at each age by the mean weight of fish in the samples. Two age groups, 1 and 2, accounted for over 95% of the total weight of the catch. The annual variation ranged from 95.0 to 99.3%. Age-1 fish contributed from 49 to 88%, and averaged 63% for the 10-yr period. Age-2 fish contributed from 12 to 50% and averaged 34%. Age-3 fish contributed an average of 2.6%, and age-0 fish 0.2% (Table 8).

Table 5.—Estimated number (in millions) of Gulf menhaden at each age landed annually, 1964-73, at plants in eastern area (Mississippi and Florida), central area (Empire to Intracoastal City, La.), and western area (Cameron, La., and Sabine Pass, Tex.).

Year	Plant location	Age				Total	Percent
		0	1	2	3		
1964	Eastern	0.52	1,194.52	219.84	5.65	1,420.53	31
	Central	0.33	744.39	768.45	88.23	1,601.40	34
	Western	5.42	1,196.65	376.86	18.04	1,596.97	35
	Total	6.27	3,135.56	1,365.15	111.92	4,618.90	100
1965	Eastern	0.35	1,702.82	297.33	8.34	2,008.84	34
	Central	41.01	1,830.84	627.35	62.04	2,561.24	43
	Western	5.27	1,354.41	41.58	1.01	1,402.27	23
	Total	46.63	4,888.09	966.26	71.39	5,972.35	100
1966	Eastern	5.13	846.22	193.10	7.00	1,051.45	26
	Central	39.17	858.08	413.77	18.53	1,329.55	33
	Western	2.54	1,422.49	243.26	5.44	1,673.73	41
	Total	46.84	3,126.79	850.13	30.97	4,054.73	100
1967	Eastern	1.32	1,007.79	84.97	4.34	1,098.42	25
	Central	17.38	1,759.82	198.98	6.21	1,982.39	44
	Western	0.00	1,361.63	25.93	0.00	1,387.56	31
	Total	18.70	4,129.24	309.88	10.55	4,468.37	100
1968	Eastern	0.00	463.78	276.61	4.46	744.85	18
	Central	23.87	1,105.98	529.02	21.22	1,680.09	40
	Western	11.53	1,741.75	44.36	1.53	1,799.17	42
	Total	35.40	3,311.51	849.99	27.21	4,224.11	100
1969	Eastern	3.16	1,320.30	150.70	6.68	1,480.84	22
	Central	7.62	2,309.13	628.31	21.77	2,966.83	44
	Western	0.00	2,137.41	232.04	1.94	2,371.39	34
	Total	10.78	5,766.84	1,011.05	30.39	6,819.06	100
1970	Eastern	0.89	690.35	299.14	2.51	992.89	19
	Central	20.89	1,050.08	1,416.42	26.07	2,513.26	48
	Western	27.60	1,515.92	481.62	5.84	2,030.98	33
	Total	49.18	3,256.35	2,197.18	34.42	5,537.13	100
1971	Eastern	1.75	952.68	532.99	65.88	1,453.30	19
	Central	7.21	2,486.21	988.76	95.04	3,577.22	46
	Western	16.30	2,424.43	316.32	9.01	2,766.06	35
	Total	25.26	5,763.32	1,838.07	169.73	7,796.58	100
1972	Eastern		788.13	171.57	11.56	971.26	20
	Central	15.31	717.13	1,223.77	52.65	2,008.86	41
	Western	2.26	1,640.99	220.33	7.43	1,871.01	39
	Total	17.57	3,146.25	1,615.67	71.64	4,851.13	100
1973	Eastern	55.66	432.33	224.56	9.39	721.94	17
	Central	1.56	1,246.38	656.45	94.92	1,999.31	47
	Western	0.00	1,333.64	201.64	5.17	1,540.45	36
	Total	57.22	2,012.35	1,082.65	109.48	4,261.70	100
Mean total		31.39	3,953.63	1,208.60	66.79	5,260.41	

Table 6.—Age composition, in percentage and numbers of fish, of Gulf menhaden in samples of the catch from all ports combined, 1964-73.

Year		Age 0	Age 1	Age 2	Age 3	Total
1964	Number	24	8,012	3,887	342	12,265
	Percent	0.2	65.3	31.7	2.8	100
1965	Number	114	12,370	2,510	213	15,207
	Percent	0.7	81.4	16.5	1.4	100
1966	Number	172	9,669	2,496	92	12,429
	Percent	1.4	77.8	20.1	0.7	100
1967	Number	93	12,590	1,320	62	14,065
	Percent	0.7	89.5	9.4	0.4	100
1968	Number	123	10,348	4,679	142	15,292
	Percent	0.8	67.7	30.6	0.9	100
1969	Number	62	12,241	2,633	103	15,039
	Percent	0.4	81.4	17.5	0.7	100
1970	Number	89	6,750	3,511	52	10,402
	Percent	0.9	64.8	33.8	0.5	100
1971	Number	20	5,402	2,092	138	7,652
	Percent	0.3	70.6	27.3	1.8	100
1972	Number	67	6,839	2,764	210	9,880
	Percent	0.7	69.2	28.0	2.1	100
1973	Number	132	5,769	2,892	153	8,946
	Percent	1.5	64.5	32.3	1.7	100

Table 7.—Mean fork length (mm) and weight (g) of Gulf menhaden in combined samples of the catch from all ports, by age, 1964-73.

	Length at age				Weight at age			
Year	0	1	2	3	0	1	2	3
1964	120	154	184	201	36	72	131	183
1965	116	147	181	204	33	65	131	192
1966	116	155	182	203	31	79	130	178
1967	102	151	181	203	22	69	122	170
1968	111	157	182	214	27	79	125	207
1969	123	147	186	207	42	66	137	198
1970	110	160	181	208	31	83	125	189
1971	119	157	188	204	31	79	140	180
1972	108	161	187	209	26	82	136	182
1973	121	165	187	213	36	101	148	217
Mean	115	155	184	207	32	78	133	190

Table 8.—Estimated weights (thousands of metric tons) and percent ages of each age of Gulf menhaden landed in the purse seine and the actual weight of fish caught, 1964-73.

Year		Age 0	Age 1	Age 2	Age 3	Total	Actua
1964	Weight	0.23	225.76	178.83	20.48	425.30	79.4
	Percent	0.1	53.1	42.0	4.8	100.0	
1965	Weight	1.54	317.72	126.58	13.71	459.55	463.1
	Percent	0.4	69.1	27.5	3.0	100.0	
1966	Weight	1.45	247.02	110.52	5.51	364.50	
	Percent	0.4	67.8	30.3	1.5	100.0	
1967	Weight	0.41	284.92	37.81	1.79	324.93	317.3
	Percent	0.1	87.7	11.6	0.6	100.0	
1968	Weight	0.96	261.61	106.25	5.63	374.45	
	Percent	0.2	69.9	28.4	1.5	100.0	
1969	Weight	0.45	380.61	138.51	6.02	525.59	523.7
	Percent	0.1	72.4	26.4	1.1	100.0	
1970	Weight	1.52	270.28	274.65	6.51	552.96	
	Percent	0.3	48.9	49.6	1.2	100.0	
1971	Weight	0.78	455.30	257.33	30.59	744.00	28.2
	Percent	0.1	61.2	34.6	4.1	100.0	
1972	Weight	0.46	257.99	219.73	13.04	491.22	501.7
	Percent	0.1	52.5	44.7	2.7	100.0	
1973	Weight	2.06	304.25	160.23	23.75	490.29	
	Percent	0.4	62.1	32.7	4.8	100.0	
Mean	Weight	0.99	300.55	160.04	12.70	474.28	471.0
	Percent	0.2	63.4	33.7	2.7	100.0	

Table 9.—Mean lengths (mm) of age-1 and -2 Gulf menhaden in purse seine catches, by degrees of longitude, 1964-73. Longitude 89a is east of the Mississippi delta, 89b is west.

		Longitude (°W)						
Year	Age	88	89a	89b	90	91	92	93
1964	1	151	153	162	156	158	151	153
	2	175	178	189	182	182	181	183
1965	1	138	141	149	150	162	151	152
	2	170	176	186	182	187	179	183
1966	1	158	157	157	156	162	151	151
	2	175	178	183	183	184	177	179
1967	1	146	150	146	151	158	150	149
	2	181	181	178	181	183	175	179
1968	1	160	156	154	141	164	155	155
	2	176	183	186	183	185	182	180
1969	1	146	147	141	150	151	156	146
	2	184	185	187	184	188	187	184
1970	1	163	160	—	158	161	168	157
	2	177	179	—	183	185	178	178
1971	1	155	155	—	158	162	159	151
	2	186	186	—	190	191	188	185
1972	1	159	162	153	154	163	166	158
	2	177	182	187	191	193	186	183
1973	1	159	164	161	166	167	164	159
	2	183	186	195	186	184	184	180
Mean	1	154	155	153	154	161	157	153
	2	178	181	186	185	185	182	181

AGE AND SIZE DISTRIBUTION BY LONGITUDE

To determine if fish were stratified by age and size along an east-west axis, I calculated the mean age and mean length of each age for each degree of longitude (dividing 89 into two parts: 89a east and 89b west of the delta) by month and year. For summarizing mean lengths I combined all months; for summarizing mean ages I grouped longitudes into three areas: eastern (84-89a), central (89b-91), and western (92-94). Too few samples were obtained from longitudes 84°-87° and 94° to calculate useful mean lengths for each longitude.

There were some differences in mean lengths by longitude, but they were small and not consistant for either age-1 or -2, although 10-yr means of age-2 fish were slightly greater for central longitudes (89b-91) than for the others (Table 9). Monthly means showed no trends.

The mean age tended to be highest in the central area and lowest in the western (Table 10). In all years it was lowest in the western area. In 6 of 10 yr it was hig the central than in the eastern area and in the othe it was about the same in both areas. In 1967, when the mean age was about the same in all areas, the fishery was dominated by the 1966 year class, which compose of the fish caught. Monthly means generally declin the season progressed.

Table 10.—Mean ages of Gulf menhaden by month and area, 1967-73.

Area (long.)	Month	Year 1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	Mean
Eastern (84-89a)	Apr.	1.38	1.24	1.05	1.16	1.65	1.34	—	—	—	1.74	1.37
	May	1.31	1.26	1.14	1.15	1.64	1.16	1.32	1.68	1.42	1.61	1.37
	June	1.13	1.10	1.27	1.16	1.48	1.21	1.27	1.41	1.44	1.64	1.31
	July	1.15	1.08	1.36	1.14	1.45	1.14	1.22	1.51	1.40	1.62	1.31
	Aug.	1.09	1.11	1.14	1.18	1.44	1.11	1.19	1.46	1.36	1.53	1.26
	Sept.	1.01	1.13	1.06	1.06	1.17	1.02	1.22	1.27	1.36	1.58	1.19
	Oct.	1.11	—	—	—	1.26	1.05	—	1.33	1.20	1.56	1.25
	Mean	1.17	1.15	1.17	1.14	1.44	1.15	1.24	1.44	1.36	1.61	1.29
Central (89b-91)	Apr.	2.10	1.73	1.00	—	1.95	—	—	—	—	—	1.70
	May	1.82	1.59	1.60	1.13	1.52	1.18	1.89	—	1.38	1.88	1.53
	June	1.68	1.33	1.38	1.03	1.41	1.23	1.59	1.44	1.51	1.58	1.42
	July	1.50	1.27	1.45	1.03	1.43	1.23	1.56	1.47	1.81	1.54	1.43
	Aug.	1.51	1.29	1.28	1.10	1.47	1.14	1.31	1.37	1.68	1.65	1.38
	Sept.	1.36	1.00	1.25	1.07	0.99	1.48	1.61	1.46	1.48	1.17	1.29
	Oct.	—	—	—	1.00	1.06	1.30	1.13	—	—	—	1.12
	Mean	1.70	1.37	1.33	1.06	1.40	1.26	1.52	1.43	1.57	1.56	1.42
Western (92-94)	Apr.	—	—	1.00	1.00	—	1.00	—	—	—	—	1.00
	May	1.33	1.15	1.42	1.07	1.17	1.00	1.66	1.39	—	1.10	1.25
	June	1.53	1.03	1.04	1.13	1.15	1.26	1.44	1.28	1.29	1.03	1.22
	July	1.53	1.03	1.04	1.13	1.15	1.26	1.44	1.28	1.19	1.03	1.22
	Aug.	1.43	1.01	0.99	1.02	1.05	1.20	1.32	1.02	1.15	1.32	1.15
	Sept.	1.10	0.92	0.79	1.00	0.99	1.09	1.01	0.99	1.17	1.30	1.04
	Oct.	1.00	—	—	—	1.00	1.00	1.00	—	1.08	—	1.02
	Mean	1.30	1.03	1.05	1.05	1.09	1.12	1.13	1.19	1.18	1.16	1.13

Table 11.—Mean lengths (mm) of Gulf menhaden of all ages and percentages of age-1 fish in samples of purse seine catches, by port, 1964-73.

Year	Mean and percent	Port Moss Pt. Miss.	Empire La.	Dulac La.	Morgan City, La.	Intracoastal City, La.	Cameron La.
1964	Mean length	156	176	—	168	—	161
	% Age-1	84	40	—	62	—	73
1965	Mean length	145	157	165	168	161	152
	% Age-1	85	70	69	70	89	97
1966	Mean length	162	166	170	169	—	152
	% Age-1	83	68	57	65	—	86
1967	Mean length	151	163	160	158	—	150
	% Age-1	91	79	90	87	—	99
1968	Mean length	166	169	175	174	159	154
	% Age-1	60	49	33	57	80	96
1969	Mean length	152	153	—	169	167	152
	% Age-1	85	85	—	69	71	86
1970	Mean length	168	—	168	173	173	165
	% Age-1	72	—	53	43	46	73
1971	Mean length	168	—	168	179	170	158
	% Age-1	60	—	71	63	71	84
1972	Mean length	164	173	182	186	185	162
	% Age-1	85	51	37	15	26	89
1973	Mean length	169	180	177	184	—	163
	% Age-1	57	45	75	55	—	87

Mean lengths and weights of all ages combined also ended to be greater in the center of the fishing area, mean ages were greater and catches contained a igher proportion of older, larger fish. The variation was imilar to, but less than that for mean ages. Monthly s showed similar trends.

ports in the center of the fishery (Empire to Intraoastal City) mean lengths were greater than at ports in the eastern (Moss Pt.) or western (Cameron) areas, and the percentage of age-1 fish in most cases was less (Table 11). The tendency of fish to be older and larger at ports in the center of the fishery probably reflects the tendency of vessels to fish most often in areas close to their home ports. The percentage of age-1 fish tended to be greatest at Intracoastal City, the most western port in the central area, than at other ports in the central area, but smaller than at Cameron.

RECRUITMENT AND RELATIVE ABUNDANCE

Fish usually enter the fishery at age-1 at a minimum size of about 120 mm, although some age-0 fish enter at about the same size in September and October. Since some age-1 fish are still less than 100 mm in July, as shown by catch samples, a year class probably is not fully recruited until August or September. The removal of large and the recruitment of small age-1 fish during the fishing season tends to supress the amount of increase in the mean and modal lengths during the fishing season relative to actual growth.

If age groups are distributed equally in time and space throughout a fishery and if the distribution of fishing effort does not change each year, the catch per unit of effort (CPUE) for each age group is an estimate of relative year class abundance. Since these conditions are closely approximated in the Gulf menhaden fishery, I based estimates of year class abundance on the CPUE of each age group. As a measure of effort, I used the adjusted vessel week[2] which was calculated from the CPUE of a selected group of vessels and the total catch of all vessels.

For the period covered, there was relatively little variation in year class abundance (Table 12). The total CPUE of all ages in a year class combined ranged from 2.577 million fish per week for the 1965 year class to 5.377 million for the 1968 year class, with a mean of 3.742 million for all years. The most abundant year classes appeared to be the 1964, 1968, and 1970, the least abundant the 1965 and 1971. On the basis of the CPUE of age-2 fish only, the 1962 year class also was probably strong.

There also was little variation in overall abundance. The CPUE for total number of fish, regardless of age, averaged 3.63 million for the 10 yr and ranged from 2.95 (1973) to 4.60 million (1969). Years of greatest relative abundance were 1965, 1969, and 1971 (4.42, 4.60, and 4.38 million, respectively); years of least abundance were 1966, 1972, and 1973 (3.02, 3.01, and 2.95 million, respectively).

Table 12.—Catch per unit of effort (millions of fish) of Gulf menhaden, at each age, 1962-72 year classes.

Year class	Age 1	Age 2	Age 3	Total
1962	—	1.175	0.053	—
1963	2.698	0.715	0.023	3.436
1964	3.618	0.633	0.008	4.259
1965	2.330	0.227	0.020	2.577
1966	3.025	0.627	0.021	3.673
1967	2.442	0.682	0.022	3.146
1968	3.891	1.392	0.094	5.377
1969	2.062	1.034	0.045	3.141
1970	3.241	1.006	0.076	4.323
1971	1.959	0.750	—	—
1972	2.088	—	–	—

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Ichthyoplankton Composition and Plankton Volumes From Inland Coastal Waters of Southeastern Alaska, April-November 1972

Chester R. Mattson and Bruce L. Wing

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Ichthyoplankton Composition and Plankton Volumes From Inland Coastal Waters of Southeastern Alaska, April-November 1972

CHESTER R. MATTSON AND BRUCE L. WING[1]

ABSTRACT

Eighteen families of fish were represented in 119 plankton samples taken on monthly cruises from April to November 1972 in southeastern Alaska. Fifteen kinds of larval fish were identified to species. Abundance of larval fish, fish eggs, and total plankton biomass peaked in May and declined through the summer. Walleye pollock (family Gadidae) were the most abundant larvae in May and June and were more concentrated in large channels than in small bays. Osmeridae and Bathylagidae were the second and third most abundantly represented families; peak abundance for both was in June and July. Other families with distinct peaks in abundance were Agonidae and Ammodytidae in May; Cottidae, Cyclopteridae, Stichaeidae, and Pleuronectidae in June; and Scorpaenidae in July. Small numbers of Bathymasteridae were present from May through July. Myctophidae, Zoarcidae, and Hexagrammidae did not show distinct changes in seasonal abundance. Clupeidae, Gasterosteidae, Pholidae, and Ptilichthyidae were too rare in the catches to exhibit seasonal abundance. Calanoid copepods and phytoplankton made up most of the plankton retained by 0.333-mm mesh nets.

INTRODUCTION

is report presents data on the kinds, distribution, and numerical abundance of ichthyoplankton and on total net plankton biomass in northern southeastern a. The data are from an 8-mo study, April-November 972. The study was intended to develop sampling methods, schedules, and station patterns for routine surveys in Alaska coastal waters. The stations represented basic types of marine environment in southeastern Alaska—enclosed bays, middle of deep channels, and the margin, or edge, of channels. Stations were grouped from to south so that differences in species distribution bundance within and between geographical and environmental areas could be evaluated. Funding and manpower restrictions imposed after completion of the work have limited sample analyses to one sample ation per month (approximately one quarter of the samples taken). The data have not been subjected to intensive interpretative analyses but are presented here in ninary form to make them available to other workers, because published ichthyoplankton data for the area are limited to the small amount in Wing and Reid (19[illegible]) for Auke Bay.

METHODS

ht monthly cruises, extending from April into November 1972, were made aboard the MV *Murre II.* The first cruise, 10-14 April, was a test to determine how many stations could be occupied in a week. As a result, a total of 21 stations were selected that could be sampled in 2-wk cruises (Table 1); five of the original April stations were deleted and replaced by others more convenient to cruise routing (Fig. 1). A northern cruise, con-

Table 1.--Location, bottom depth at station, proposed sampling depth, and habitat category of plankton stations routinely occupied in southeastern Alaska, April-November 1972. (B = Bay, C = midchannel, E = margin of channel).

Station						
No.	Name	Habitat	Lat. N	Long. W.	Bottom depth range (m)	Target sampling depth (m)
1	Dyea	C	59°27.9'	135°21.5'	115-164	100
2	Taiya	C	59°17.9'	135°22.8'	102-343	200
3	Haines	E	59°13.2'	135°23.1'	80-128	100
4	Chilkoot Inlet	C,E	59°04.8'	135°14.6'	47-247	100
5	Chilkat Inlet	C,E	59°04.7'	135°20.4'	113-208	100
6	Berners Bay	B	58°41.4	134°56.7'	50-90	50
7	Mid-Lynn Canal	C	58°41.4'	135°03.1'	250-130	200
8	Danger Point	E	58°41.4'	135°11.1'	73-130	100
9	Point Retreat	C	58°25.7'	135°00.0'	265-426	300
10	Saginaw Channel	E	58°24.0'	134°53.4'	22-120	50
11	Favorite Channel	E	58°22.0'	134°45.3'	46-100	50
12	Auke Bay	B	58°21.9'	134°40.0'	43-64	50
13	Gambier Bay	B	57°28.7'	134°00.8'	46-90	75
14	False Point Pybus	E	57°24.2'	133°52.2'	47-123	50
15	South Stephens Passage	C	57°23.7'	133°36.1'	221-315	250
16	Farragut Bay	B	57°07.4'	133°10.2'	77-90	60
17	Grand Point	C	57°03.2'	133°13.2'	166-176	150
18	Boulder Point	E	57°01.0'	133°15.0'	50-181	60
19	Cornwallis Point	C	56°56.7'	134°17.7'	98-190	100
20	Saginaw Bay	B	56°52.9'	134°11.0'	36-86	50
21	Red Bluff	C	56°50.0'	134°34.6	550-713	300

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hwest and Alaska Fisheries Center Auke Bay Laboratory, National Marine Fisheries Service, NOAA, P.O. Box 155, Auke Bay, AK 99821.

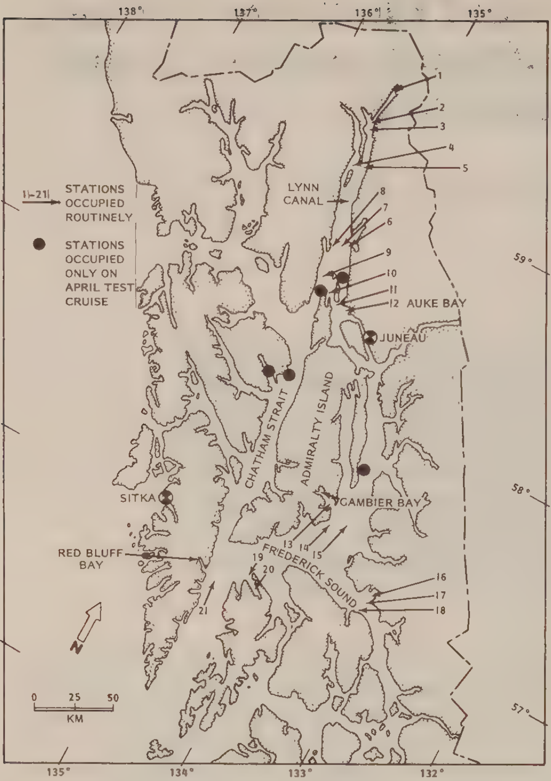

Figure 1.—Location of plankton and oceanographic sampling stations occupied monthly in southeastern Alaska, April-November 1972.

sisting of stations 1-12, extended southerly from Dyea in northern Lynn Canal to Auke Bay, located about 19.3 km northwest of Juneau. A southern cruise, stations 13-21, ranged from Gambier Bay on Admiralty Island to the junction of Frederick Sound and Chatham Strait near Red Bluff Bay. The only months when all stations could be sampled were May, June, and July. Beginning in August, stormy weather reduced sampling to 18 stations in August, 15 stations in September, 16 stations in October, and only 7 stations in November.

Before sampling for zooplankton, we completed a standard oceanographic station including surface observations (wind, wave, cloud cover, temperatures, barometric pressure, and water transparency), subsurface observations (temperature, salinity, oxygen, phosphates, nitrates, silicates, and chlorophyll a), and a surface phytoplankton collection. The physical and chemical observations are on file at the National Oceanographic Data Center, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Rockville, MD 20852, and data on the phytoplankton composition were reported by Williamson.[2]

Zooplankton samples were collected with a bongo array consisting of a 20-cm (mouth diameter) frame equipped with 0.253- and 0.333-mm mesh nets placed 1.0 m above a 61-cm frame equipped with 0.333- and 0.5 mm mesh nets. A 1.2-m Braincon type 275 v-fin depr sor was suspended 1 m below the larger bongo frame. Sampling depths were recorded with a Bendix Model T1 bathykymograph of 300-m depth range. Gene Oceanics Model 2030 digital flowmeters were used to timate water filtered.

Sampling technique was a single oblique tow in dep over 150 m, and multiple oblique tows in shallow dep (100 m or less). Target sampling depths ranged from m in shallow bays and channel margins to 300 m at the deepest channel stations (Table 1). Towing was at a c stant surface speed of 2 kn (1.029 m/s). Tow cable served out at 60 m/min and retrieved at 20 m/min, while rates were monitored by stopwatch and cable amounts by a dial-reading meter wheel. When necessary, wi speed changes were made verbally to the winch operat Towing times ranged from 12 to 47 min, depending upon target depth and maneuvering room within confined bays. Towing distances ranged from 0.7 km (0.4 n.mi. 2.9 km (1.6 n.mi.). When multiple shallow oblique t were made, the nets were raised until visible, checked for debris or plugging, then lowered. Upon tow completi all samples were preserved in 3-5% unbuffered seaw formaldehyde.

For processing, the samples were taken to the laboratory where the formaldehyde was buffered wit saturated borax solution. We processed only the catc by the 61-cm, 0.333-mm mesh net. Each sample was sorted in its entirety under a dissecting microscope at magnifications of 7-10×. All fish eggs and fish lar were removed and counted. Only the fish larvae w identified. Notes were kept on the abundance rank of general plankton categories. Total settling volumes of plankton were estimated to the nearest 25 ml i graduated 0.95-liter (1 qt) widemouth bottle.

The data were converted to standardized tows as numbers under 10 m^2 of water surface (computed as num per 10 m^3 per meter of tow depth (Ahlstrom 1948)) larval fish and eggs and to milliliters per 1,000 m water filtered for the plankton settling volumes.

RESULTS

One hundred twenty-six plankton tows were c pleted at the regular stations of which 119 were sorted fish eggs and fish larvae (Table 2). Three samples, station 13 in May and stations 13 and 14 in June, processed for plankton volumes but not for icht plankton because of exceptionally high quantities phytoplankton. Samples from four tows could not be processed because they contained large amounts of ion 10, May; stations 4 and 14, August) or surface trash (station 15, September) (Appendix 1).

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[2] Williamson, R. 1974. Phytoplankton species and their geographical distribution in southeast Alaska. Northwest and Alaska Fisheries Center Auke Bay Laboratory, National Marine Fisheries Service, NOAA, Auke Bay, AK 99821. Unpubl. manuscr.

tive Abundance of Fish Eggs

A total of 18,354 fish eggs were sorted from 119 samples (Table 2). During the peak month of May, a tenfold dif- ce in abundance was evident between the northern stations (averaging 2,072.2 eggs/10 m^2) and the southern stations (averaging only 210.1 eggs/10 m^2). Exceptionally high egg counts were obtained from the Taiya (station 2) and Berners Bay (station 6) samples. Exceptions to the May peak abundance were evident in Saginaw Channel (station 10) and Farragut Bay (station 16), where maximum numbers occurred in July. The 1972 peak egg abundance in May contrasts to a previous

--Abundance of larval fish and fish eggs (number per 10 m^2) collected with 61-cm, 0.333-mm-mesh Bongo net at 21 stations in southeastern Alaska, April-November 1972. In fish listed only to family, the species were not identified.

	Station	Habitat	Station totals Fish eggs	Station totals Fish larvae	Clupea harengus pallasi	Thaleichthys pacificus	Other Osmeridae	Bathylagus stilbius schmidti	Stenobrachius leucopsaurus	Theragra chalcogramma	Other Gadidae	Zoarcidae	Gasterosteus aculeatus	Scorpaenidae	Hexagrammidae	Cottidae	Agonidae	Cyclopteridae	Bathymasteridae	Stichaeidae	Ptilichthys goodei	Pholidae	Ammodytes hexapterus	Glyptocephalus zachirus	Hippoglossoides elassodon	Lepidopsetta bilineata	Limanda aspera	Parophrys vetulus	Platichthys stellatus	Psettichthys melanostictus	Other Pleuronectidae	Unidentified larvae
April	11	E	--	16.5	--	--	1.0	2.9	--	--	--	--	--	--	1.9	--	--	1.9	--	--	--	--	--	--	4 9		--	--	--	--	1.0	--
	19	E	--	28.8	--	--	--	8.2	--	--	--	--	--	4.1	2.1	8.2	--	2.1	--	--	--	--	4.1	--	--	--	--	--	--	--	--	--
	20	B	3.2	41.7	--	--	--	33.8	--	1.6	--	1.6	--	0.8	0.8	0.8	0.8	1.6	--	--	--	--	--	--	--	--	-	--	--	--	--	--
	21	C	--	48.0	--	--	--	--	4.8	--	--	28.8	--	4.8	--	--	--	9.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	1	C	1926.6	1858.2	--	5.6	--	--	--	1693.1	--	--	--	18.8	1.9	15.0	3.8	1.9	--	31.9	--	1.9	77.0	--		--	--	--	--	3.8	--	3.8
	2	C	6233.6	4513.3	--	5.1	--	--	5.1	4293.1	--	--	--	7.7	2.6	46.1	2.6	5.1	20.5	48.6	--	--	69.1	--	--	7.7	--	-	--	--	--	--
	3	E	1401.3	2108.0	--	--	--	0.8	--	2024.9	--	--	--	--	0.8	13.6	0.8	12.8	0.8	24.9	--	--	17.4	--	--	3.8	--		--	--	2.3	5.3
	4	C,E	1322.5	2389.4	--	--	--	1.1	--	2326.4	--	--	--	--	--	5.7	4.6	5.7	--	14.9	--	--	13.8	--	--	-	--	--	2.3	--	--	14.9
	5	C,E	2299.9	2070.8	--	--	--	1.3	--	2023.7	--	--	--	7.9	1.3	10.5	--	3.9	--	9.2	--	--	2.6	--	-	--	--	1.3	--	3.9	--	5.2
	6	B	4010.1	477.9	--	--	--	7.5	--	383.5	--	--	--	--	--	24.0	10.5	3.0	--	15.0	--	--	28.5	--	--	4 5	--	--	--	--	1.5	--
	7	C	1448.5	1448.5	--	--	--	32.3	--	1390.4	--	--	--	6.5	--	3.2	3.2	--	--	9.7	--	--	--	--	--	--	--	--	-	--	--	3.2
	8	E	749.0	2465.7	--	--	--	53.4	--	2362.5	--	--	--	--	--	8.9	--	7.1	--	17.8	--	--	1.8	--	--	--	--	-	--	--	12.3	--
	9	C	352.9	1315.1	--	--	--	26.0	3.7	1226.0	--	3.7	--	3.7	--	48.3	--	--	3.7	--	--	--	--	--	--	--	--	--	--	--	--	--
	1	E	2160.9	102.3	--	--	--	--	--	78.9	--	--	-	--	--	--	--	11.7	--	--	--	--	2.9	--	--	--		--	--	--	11.7	--
	2	B	544.4	153.2	--	--	--	2.5	--	37.7	1.3	--	--	--	--	25.3	7.6	6.3	1.3	60.8	--	--	3.8		--		--	--	-	--	2.5	5.1
	4	E	108 1	60.3	--	--	--	7.5	--	27.6	--	--	--	--	2.5	--	--	5.0	5.0	12.6	--	--	--	--	--	--	--		--	--	--	--
	5	C	160.5	196.2	--	--	--	53.5	--	83.2	--	5.9	--	--	--	35.7	--	--	--	5.9	--	--	--	-	--	-	--	--	-	--	--	--
	6	B	512.1	225.4	-	--	94.0	--	--	1.0	--	--	--	1.0	--	1.0	--	2.9	--	15.3	--	--	110.3	--	--	--	--	--	-	--	--	--
	7	C	231.1	142.5	--	--	--	--	--	92.4	--	--	--	15.4	--	11.6	--	3.9	--	--	--	--	3.9	--	--	--	--	--	--	--	--	15.4
	18	E	47.0	500.3	--	--	6.4	19.2	2.1	395.5	--	--	--	2.1	2.1	25.7	10.7	29.9	2.1	--	--	--	2.1	--	--	--	--	--	--	--	--	--
	19	E	165.2	156.3	--	2.2	--	2.2	--	140.7	--	--	--	4.5	--	--	--	--	--	4.5	2.2	--	--	--	--	-	-	--	--	--	--	--
	20	B	45.7	402.1	--	--	54.8	--	--	322.9	--	--	--	12.2	--	--	--	3.0	--	3.0	--	--	6.1	--	-	--	--	--	--	--	--	--
	21	C	167.6	5444.4	--	--	--	93.1	6.2	4966.4	--	15.5	--	18.6	34.1	--	--	--	239.0	71.4	--	--	--	--	-	--	--		--	--	--	--
	1	C	52.2	266.0	--	7.1	173.9	--	--	41.2	--	--	--	--	--	14.2	--	0.6	0.6	7.7	--	--	5.6	--	12.2	--	--	--	3.3	--	3.3	0.6
	2	C	83.3	412.6	--	3.9	48.4	7.7	--	246.0	--	--	--	3.9	--	27.1	--	17.4	--	21.3	--		5.8	--	11.6	--	5.8	--	--	9.7	--	--
	3	E	171.1	539.5	--	--	6.8	8.5	--	415.3	--	--	--	--	--	16.2	--	25.5	2.6	35.7	--	--	11.9	--	--	--	--	--	--	4.3	12.8	--
	4	C,E	76.7	468.9	--	--	22.6	27.9	--	363.2	--	--	--	1.5	--	1.5	--	9.8	7.6	27.9	--	--	3.0	-	--	--	--	--	-	1.5	2.3	--
	5	C,E	35.9	404.6	-	--	4.8	16.8	--	344.7	--	--	--	--	--	2.4	--	6.0	--	21 5	-	--	4.8	--	2.4	-	1.2	-	--	--	--	--
	6	B	547.0	717.3	--	4.5	105.5	128.1	--	458.1	--	--	--	--	--		--	3.0	--	12.1	--	-	3.0	--	--	--		--	--	3.0	--	--
	7	C	20.8	526.8	--	--	47.6	95.2	8.9	315.5	--	8.9	--	3.0	--	20.8	--	3.0	3.0	6 0	--	--	14.9	--	--	-	--	-	--	--	--	--
	8	E	28.4	191.4	--	2.8	--	21.3	--	143.2	--	--	--	--	--	1.4	--	5.7	--	11 3	--	-	--		2.8	--	-	--	--	2.8	--	--
	9	C	0	130.6	--	--	--	37.3	3.7	26.1	--	3.7	--	3.7	--	22.4	--	--	--	--	-	--	26.7	--	--	-	--	-	--	--	3.7	3.7
	10	E	67.7	255.5	--	1.9	15.4	63.4	--	155.6	--	--	--	3.8	--	1.9	--	3.8	--	9.6	--	--	--	-	--	--	--	-	--	--	--	--
	11	E	259.9	313.6	--	9.0	180.8	22.6	--	68.4	--	--	--	0.6	--	2.8	1.1	10.7	2.3	5.1		--	--	--	2.8	-	--	--	6.2	0.6	0.6	
	2	B	108.8	337.1	--	0.6	136.7	3.2	--	146.3	--	--	--	3.2	--	6.4	1.9	6.4	--	18.4	--	--	4.5	-	3 2	--	--	--	--	--	5.1	1.3
	5	C	6.3	31.5	--	4.2	-	4.2	4.2	2.1	--	2.1	--	--	--	8.4	--	5.9	--	2.1		--	5.9	--	--		--	-	--	--	4.2	--
	6	B	843.5	460.2	-	43.2	198.0	--	--	150.6	--	--	--	--	--	14.7	--	3.2	--	47.4	--	--	--	--	-	--	-	--	--	--	3.2	--
	7	C	18.5	172.0	--	10.6	--	--	--	13.2	--	--	--	21.2	7.9	23.8	--	2.6	10.6	63.5	2.6	-	15.9	--	--	--	--	--	--	--	--	--
	8	E	22.1	166.0	--	7.9	0.9	10.6	--	12.4	--	--	--	33.6	--	38.9	0.9	7.1	41.5	2.1	--	--	--	--	9.7	--	--	-	--	--	--	0.9
	9	E	0	28.8	--	--	--	--	--	6.8	--	--	--	15.1	--	--	--	--	--	6.8	--	--	--		--	--	--	--	--	--	--	--
	20	B	6.7	327.1	--	--	101.8	--	--	125.5	--	--	--	2.9	--	38.0	4.8	3.8	--	33 3	--	--	1.0	1.0	4 8	--	--	--	--	4.8	1.9	3.8
	21	C	111.9	402.2	--	3.5	--	56.0	--	49.0	--	45.5	--	216.8	14.0	--	--	10.5	--	7.0	--	--	--	--	--	--	--	--	--	--	--	--
July	1	C	32.8	149.2	--	12.7	98.4	16.9	1.1	--	--	--	--	2.1	--	2.1	--	1.1	--	--	--	--	5.3	--	1 1	--	--	3.2	2.1	2.1	--	--
	2	C	120.0	442.7	--	34.7	298.7	45.3	2.7	18.7	-	--	--	--	--	--	--	5.3	16.0	2.7	--	--	10.7	--	--	--	--	--	--	--	--	5.3
	3	E	62.2	234.1	1.0	5.2	120.2	31.1	--	32.1	--	--	--	2.1	--	12.4	--	7.3	5.2	2.1	--	--	1.0	--	--	-	--	8.3	--	5.2	--	1.0
	4	C,E	39.5	163.7	--	5.9	63.9	69.7	--	24.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-	--	--	--	--	--	--	--
	5	C,E	0	365.5	--	69.5	108.1	61.8	--	77.2	--	--	-	12.9	--	1.3	--	1.3	6.4	5.1	--	--	5.1	--	7 7	-	-	7.7		--	1.3	1.3
	6	B	134.2	238.3	--	105.6	--	104.1	--	7.5	--	--	--	--	--	3.0	1.5	3.0	--	--	--	-	--	--	7.5	-	--	--	--	--	--	--
	7	C	3.1	107.3	--	--	64.4	30.7	--	3.1	--	--	--	--	--	6.1	--	--	3.1	--	--	--	--	--	-	--	--	--		--	--	--
	8	E	0	512.3	--	24.5	357.8	51.5	--	27.0	--	--	--	4.9	--	9.8	--	4.9	4.9	-	--	--	--	--	2 5	12.3	-	9.8	--	--	2.5	12.3
	9	C	8.0	147.6	--	8.0	8.0	67.8	8.0	4.0	--	8.0	--	23.9	--	--	--	8.0	8.0	--	--	--	--	--	--	-	--	--	--	--	--	--
	10	E	84.5	202.6	--	26.0	128.3	18.6	--	1.9	-	--	--	--	--	--	--	1.9	11.2	--	--	--	--		1 9	--	--	-	--	--	7.4	5.6
	11	E	187.3	907.1	--	17.0	739.3	94.8	--	2.4	--	--	--	7.3	--	7.3	--	--	24.3	--	--	--	--	--	7.3	--	--	--	--	--	2 4	4.9
	12	B	81.1	145.7	--	--	120.9	--	--	5.0	--	--	--	--	--	1.7	1.7	--	-	--	--	-	--	-	16.6		--	--	--	--	--	--
	13	B	277.5	52.0	--	2.2	10.8	--	--	2.2	--	--	--	6.5	--	8.7	--	4.3	--	15.2	-	--	--	--	--	--	--	--	--	--	--	2.2
	4	E	10.0	1.7	--	--	--	-	--	1.7	-	--	--	--	--	--	--	--	--	-	--	-	--	--	--	--	--	--	-	--	--	--
	5	C	3.3	96.4	--	--	3.3	6.7	16.6	--		--	--	63.2	--	--	--	--	3.3	--	-	-	--		--	-	--	-	--	--	3 3	--
	6	B	1290.7	504.3	--	12 2	331.8	12.2	1.1	118.3	--	--	--	2.2	--	15.5	--	3.3	7.7	--		--	--	--	--	--	--	--	--	--	--	--
	7	C	27.6	67.4	--	--	6.1	6.1	--	--	--	--	--	33.7	--	3.1	--	--	9.2	-	-	--	--	--		--		3.1	--	--	3.1	3.1
	8	E	5.7	62.5	--	--	-	4.0	--	1.4	--	--	--	38.4	--	4.3	--	2.8	5.7	1.8	--	--	4.3		--	--	--	--	-	--	--	2.8
	9	E	0.9	148.9	--	-	1.7	5.1	--	--	--	--	0.9	124.8	0.9	9.4	--	--	7.7	--	--		--	-	--		--	--	--	--	--	--
	20	B	2.3	95.3	4.5	--	35.2	-	--	1.1	--	--	--	6.8	--	7.9	--	3.4	28.4	3.4	--	--	--	--	1 1	--	-	--	--	--	3 4	--
	21	C	5.9	666.9	--	-	--	17.7	5.9	--	--	82.6	-	560.7	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--
August	1	C	0	16.8	--	2 4		2.4	2.4	--	--	--	--	--	--	2.4	--	--	--	4.8	--	--	--	--	--		--	-	--	--	2 4	--
	3	E	16.0	145.7	--	72 0	--	57.6	--	--	--	3.2	--	-	--	--	--	--	--	12.8	--	-	--	-	--	--	--	--	--	--	--	--
	5	C,E	1.3	59.9	--	12.2	--	44.9	--	--	--	--	--	--	--	--	--	--	-	--	--	--	--	--	--	--	-	--	--	--	--	2.7
	6	C	61.2	147.4	--	107 2	--	24.9	--	1.9	-	--	--	-	--	--	1.0	4.8	--	-	--	--	--	--	--		--	-	4.8	2.9	--	--
	7	B	0	73.2	--	11.7	--	43.9	14.6	--	--	--	--	--	--	--	--	--	--	-	--	--	--	--	--		--	-	--	--	--	--
	8	E	0	161.9	--	116 5	--	40.9	--	--	--	--	--	--	--	--	--	1.5	--	--	--	--	--	-	--	--	--	1.5	1 5	--	--	--
	9	C	78.6	144.2	--	3.3	22.9	9.8	26.2	--	--	26.2	3.3	3.3	36.0	--	--	3.3	--	--	--	--	--	-	--	--	--	3.3	-	6.6	--	--
	10	E	0	88.0	--	1.5	45.5	10.6	--	1.5	--	--	--	3.0	--	1.5	--	4.6	12.1	1.5	--	--	--	--	--	--	--	3.0	--	1.5	--	1.5
	11	E	20.7	37.3	-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-	--	--	--	--	--		--	--	--	--	--	37.3
	12	B	14.8	75.4	--	59.1	--	1.5	--	--	-	--	-	4.4	--	--	--	1.5	4.4	3.0	-	--	--	--	--	--		--	--	--	--	1.5
	13	B	56.9	50.9	--	9 0	-	3.0	--	26.9	--	--	--	6.0	--	--	--	--	3.0	--	--	--	--	--	--	--	--	--	3.0	--	--	--
	15	C	0	35.5	--	8.9	-	--	8.9	--	--	--	4.4	--	--	8.9	--	--	--	4.4	--	--	--	--	--	--	--	--	-	--	--	--
	6	B	12.0	115.6	--	91.7	--	--	--	15.9	--	--	--	4.0	--	4.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	8	E	0	11.1	--	--	--	--	--	--	--	--	--	3.7	--	1.8	--	3.7	1.8	--	--	--	--	--	--	--	--	--	--	--	--	--
	9	E	0	22.2	--	2.6	--	10.4	--	--	--	--	--	1.3	--	5.2	--	1.3	--	1.3	--	--	--	--	--	--	--	--	--	--	--	--
	0	B	1 6	20.7	--	--	--	--	--	--	--	--	--	1.6	--	12.7	--	--	4.7	1.6	--	--	--	--	--	--	--	--	--	--	--	--
	1	C	0	122.9	--	--	--	11.9	--	--	--	111.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Sept	1	C	0	2.2	--	1.1	--	1.1	--	--	-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	3	E	29.1	8.7	--	2.9	--	5.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	4	C,E	6.2	33.2	--	3.7	--	29.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	5	C,E	2.7	21.5	--	4.3	2.2	15.1	--	--	--	--	--	-	--	-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	9	C	3.0	47.5	--	--	--	20.8	5.9	--	--	5.9	--	8.9	3.0	--	--	3.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	0	E	0	14.7	--	--	--	2.1	2.1	--	--	--	--	2.1	8.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	1	E	18.0	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	2	B	6.8	49.7	--	4.5	43.0	--	--	--	--	--	--	--	--	--	--	--	2.3	--	--	--	--	--	--	--	--	--	--	--	--	--
	3	B	0	26.9	--	2.2	--	--	--	17.9	--	--	--	--	2.2	4.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	4	E	1.3	9.2	--	1.3	1.3	--	--	1.3	1 3	--	--	--	2.6	--	--	1.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	6	B	14.7	2.1	--	--	2.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	18	E	0	4.5	--	--	1.5	--	--	--	--	--	--	--	--	-	--	3.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	19	E	0	0	--	--	--	--	--	--	--	--	--	-	--	-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	20	B	0	6.3	--	--	3 1	-	--	--	--	--	--	--	--	3.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
October	4	C,E	12.7	11.6	--	3.5	1.2	5.8	--	--	--	--	--	--	--	--	--	1.2	-	--	--	--	--	--	--	--	--	--	--	--	--	--
	6	B	22.8	7.0	--	--	5.0		1.0	--	-	--	--	--	1.0	-	--	-	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	7	C	3.0	45.1	--	-	--	12.0	27.0	--	--	6.0	--	--	--	--	--	--	--	-	--	--	--	--	--	--	--	--	--	--	--	--
	9	C	20.9	37.7	--	--	--	16.7	12.6	--	-	--	-	--	--	--	--	8.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	0	E	3.8	1.0		-	--	--	--	--	-	--	--	--	--	--	--	--	-	--	--	--	--	--	--	--	--	--	--	--	--	1.0
	1	E	22.5	2.9	--	--	--	2.9	--	--	--	--	--	--	--	-	--	--	--	-	--	--	--	--	--	--	--	--	--	--	--	--
	2	B	25.7	5.8	--	0.9	4.4	--	--	--	--	--	--	-	--	0.4	--	--	--	-	--	--	--	--	--	--	--	--	--	--	--	--
	13	B	12.0	6.0	--	--	1.5		--	1.5	-	--	-	1.5	--	1.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	14	E	0.9	0.9	--	-	--	--	--	--	--	--	--	--	0.9	--	--	--	--	-	--	--	--	--	--	--	--	--	--	--	--	--
	15	C	0	27 2	-	-		2.7	24.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	16	B	34.2	8.9	--	--	2.5	--	--	3.8	--	--		--	2.5	--	--	--	-	--	--	--	--	--	--	--	--	--	--	--	--	--
	17	C	0	10.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-	--	--	--	--	--	--	--	--	--	--	--	10.8
	8	E	0	2.3	--	--	0.8	--	--	--		--	--	--	-		--	1.5	-	--	--	--	--	--	--	--	--	--	--	--	--	--
	9	E	0	1.0	--	--	--	--	--	--	--	--	--	--	1.0	-	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--
	0	B	0	13.5	--	-	10.1	--	--	--	--	--	--	-	--	3.4	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--
		C	2.5	9.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	9.9
nov		B	3.1	1.5	--	--	--	1.5	-	--		--	-	--	--	-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	7	C	6.7	53.4	--	--	--	30.0	13.4	--	--	--	--	--	--	6 7	3.3	--	--	-	--	--	--	--	--	--	--	--	--	--	--	--
	8	E	0	4.7	--	--	--	2.3	--	--	--	--	--	--	2.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	9	C	0	31.4	-	-	--	11.4	20.0	--	--	--	--	-	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--
	10	E	0.9	0	--	--	--	--		--	--	--	-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	11	E	7 2	1.0	--	--	1.0	--	--	--	--	--	--	--	--	--	--	--	-	--	--	--	--	--	--	--	--	--	--	--	--	--
		B	0	0.9	--	--	0.9	--	--	--	--	--	--	--	--	--	--	--	--	-	--	--	--	--	--	--	--	--	--	--	--	--

study, indicating an April peak (Wing and Reid 1972). Such a difference could result from annual variations in environmental conditions which may affect spawning times.

Larval Fish Abundance

A total of 23,819 larval and juvenile fish were sorted from 119 samples. Identification of larval fishes for the northwest Pacific Ocean, and Alaskan waters in particular, is very difficult. Therefore, we were able to identify only 15 species from 18 identified families (Table 2). Larval fishes in three families, Gadidae, Osmeridae, and Bathylagidae, contributed 87.5% of the catch in the samples processed. Walleye pollock, *Theragra chalcogramma*, the most abundant gadid, formed 68.2% of the total catch identified. Abundance of pollock was greatest in May and June when they formed 92.6% and 49.8%, respectively, of the total catch identified. Their distribution favored the channels rather than inside bays. Only three larval gadids were not walleye pollock, but unfortunately we could not identify these.

Osmerids were second in abundance, accounting for 14.9% of the total catch processed. Greatest abundance occurred in June and July (24.9% and 55.6% of the total, respectively). Eulachon, *Thaleichthys pacificus*, was the only osmerid identified to species, but capelin, *Mallotus villosus*, the most common osmerid in southeastern Alaska, was believed to compose the bulk of the osmerid samples. Greatest osmerid abundance was noted in the northern area with exceptions of Point Retreat (station 9) and Auke Bay (station 12), where they were scarce. In the southern areas, osmerids were abunda Farragut Bay (station 16) and Saginaw Bay (station 20 and scarce elsewhere.

The third most abundant species was the nor smoothtongue, *Bathylagus stilbius schmidti* (B lagidae), composing 4.5% of the total processed catch Abundance was high from May to August, peaking i June and July with 5.8% and 12.4% of the proc catch. Geographical abundance was markedly gr ter with the exception of Auke Bay, in the northern stations where they were taken in 54 of 68 samples, and av catch per haul was generally much higher than i southern stations. In the south, they were represented in only 20 of 51 samples.

Pacific herring, *Clupea harengus pallasi*, were spicuous by their absence. Although adult herrin fished commercially throughout southeastern Alaska larval herring were found only among the Haines (station 3) and Saginaw Bay (station 20) samples. Auke Bay tion 12) generally is a productive spring spawning for herring and is heavily fished in the spring for roe and bait herring. Larval and postlarval herring are known to occur in the Auke Bay area from early June through tember although our sampling did not collect the

The families Scorpaenidae, Cottidae, and Stichaeidae each contributed approximately 2% to the total c Scorpaenid abundance was greatest in July geographical distribution favored the channel r ther than bay stations. Cottid and stichaeid abundance was

Table 3.--Settling volumes in 122 samples of plankton collected with 61-cm, 0.333-mm-mesh bongo net in southeastern Alaska, April-November 1972.

Station	Milliliters per 1,000 m^3 of water filtered							
	April	May	June	July	Aug.	Sept.	Oct.	Nov.
1	--	2,174	2,146	1,199	1,284	495	--	--
2	--	2,412	2,459	2,224	--	--	--	--
3	--	2,968	1,646	1,590	1,674	654	--	--
4	--	2,126	1,114	1,451	--	855	253	--
5	--	3,447	1,496	1,422	1,105	673	--	--
6	--	346	1,412	1,412	938	--	133	149
7	--	2,258	1,687	1,819	1,768	--	2,128	1,471
8	--	5,660	3,369	882	557	--	--	218
9	--	3,120	3,937	1,616	1,039	928	1,430	1,265
10	--	--	1,753	1,673	1,858	768	199	624
11	239	7,885	484	2,027	2,203	661	255	199
12	--	1,793	742	1,159	1,594	3,141	163	170
13	--	25,000	20,000	1,084	1,701	1,402	884	--
14	--	4,583	10,000	713	--	437	201	--
15	--	860	3,131	1,031	1,820	--	1,124	--
16	--	285	421	2,046	2,057	785	328	--
17	--	883	1,597	1,267	1,448	882	2,338	--
18	--	606	1,003	987	846	281	136	--
19	257	4,583	639	1,069	573	631	228	--
20	1,505	3,311	6,002	2,041	1,005	1,031	452	--
21	374	506	1,253	843	868	--	238	--
Means	593.6	3,740.3	3,156.7	1,407.4	1,352.1	851.6	655.6	581.1

Table 4.--Predominant forms of plankton collected with 61-cm, 0.333-mm-mesh bongo net in southeastern Alaska, April-November 1972. (Cope = calanoid copepod (Chaeto = chaetognaths, Euph = euphausiids; Parath = *Parathemisto libellula*; Phyto = phytoplankton.)

Station	April	May	June	July	Aug.	Sept.	Oct.	Nov.
1	--	Phyto	Cope	Cope	Chaeto	Chaeto	--	--
2	--	Cope	Cope	Cope	--	--	--	--
3	--	Cope	Cope	Cope	Cope	Chaeto	--	--
4	--	Cope	Cope	Cope, Chaeto	--	Cope, Chaeto	Euph, Chaeto	--
5	--	Cope	Cope	Cope, Chaeto	Cope	Euph	--	--
6	--	Barnacle nauplii	Cope	Cope, Chaeto	Cope	--	Phyto	Parat
7	--	Phyto	Cope	Cope	Cope	--	Cope	Cope
8	--	Cope	Cope	Phyto	Cope	--	--	Euph
9	--	Phyto	Cope	Cope	Cope	Cope	Cope	Cope
10	--	Phyto[1/]	Cope	Cope	Phyto	Phyto	Phyto	Parat
11	Cope	Phyto	Cope	Phyto	Phyto	Phyto	Phyto	Phyto
12	--	Phyto	Cope	Phyto	Phyto	Phyto	Phyto	Phyto, Para
13	--	Phyto	Phyto	Cope	Cope	Phyto	Euph, Chaeto	--
14	--	Phyto	Phyto	Phyto	--	Phyto	Phyto	--
15	--	Cope	Phyto,	Cope	Cope	--	Cope	--
16	--	Cope	Cope	Cope	Phyto	Cope, Phyto	Phyto	--
17	--	Cope	Cope	Cope	Cope	Phyto	Cope	--
18	--	Cope	Cope	Cope	Phyto	Cope	Phyto	--
19	Cope	Phyto	Phyto	Cope	Cope	Euph	Phyto	--
20	Phyto	Phyto	Cope	Cope	Cope	Phyto	Euph, Cope	--
21	Cope	Phyto	Phyto, Cope	Phyto	Cope	--	Cope	--

[1/] From catch by 20-cm, 0.333-mm-mesh net.

st in May and June, but no geographical preference was evident.

The families Ammodytidae, Bathymasteridae, pteridae, and Pleuronectidae each contributed 1.0 to % of the total catch. Sand lance, *Ammodytes hexapterus*, were most abundant in May with a geo- hical preference for the northern stations. Bathy- erid abundance was about equal for May, June, and July followed by a significant drop in August. Cyclopterids and pleuronectids were most abundant in June. Of ess frequently collected families, agonids were most dant in May, and myctophids, zoarcids, and hexagrammids did not have distinct seasonal changes. Pholids, gasterosteids, and ptilichthyids were too rare to it any geographic or seasonal trends.

Plankton Volumes and Composition

nkton settling volumes were measured for 122 samples and converted into milliters per 1,000 m^3 of water filtered (Table 3). Maximum abundance occurred in May, when the mean was 3,740.3 ml/1,000^3, followed une with a mean of 3,156.7 ml/1,000 m^3. In July abundance had dropped sharply and then continued a consistent decline into November. In a previous study, tonic abundance in Auke Bay had peaked in June (Wing and Reid 1972), but results were not quite comparable as a larger mesh net (0.526 mm) was used which retained less phytoplankton and fewer small copepods.

Predominant forms of plankters were determined during sorting (Table 4). In order of complete biomass dominance, copepods lead with 62 samples, followed by phytoplankton in 40, and chaetognaths and euphausiids in 3 each, amphipods in 2, and barnacle nauplii in 1. Eleven samples shared dominance between two organisms. On several occasions phytoplankton clogged the nets, sharply reducing efficienty of the nets. The greatest diversity among dominant organisms occurred in November, when phytoplankton, copepods, and amphipods dominated at two stations each and euphausiids at one.

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APPENDIX

Appendix I.--Collection data for analyzed ichthyoplankton samples taken with a
cm, 0.333-mm-mesh bongo net in southeastern Alaska, April-November 1972.

Station	Date	Starting time of tow	Duration of tow (min)	Maximum sample depth (m)	Volume of water filtered (m^3
	April				
11	10	1447	30	51	524
19	13	1106	27	100	486
20	13	0852	26	34	432
21	12	1800	47	385	803
	May				
1	16	0915	29	95	506
2	16	1243	26	138	539
3	16	1424	21	42	556
4	16	1645	29	66	576
5	16	1814	25	75	573
6	17	1410	25	65	434
7	17	1236	27	>200	620
8	17	1017	26	66	371
9	18	1110	39	250	673
10	18	1300	16	40	195[1/]
11	18	1447	16	38	130
12	18	1615	16	30	237
13	27	1557	15	50	114[2/]
14	27	1413	13	46	183
15	27	1241	26	242	407
16	26	1640	17	42	438
17	26	1510	16	109	283

ndix 1.--Continued.

ion	Date	Starting time of tow	Duration of tow (min)	Maximum sample depth (m)	Volume of water filtered (m^3)
	May				
18	26	1341	25	115	538
9	25	1526	20	67	300
20	25	1703	12	46	151
1	25	1235	32	230	741
	June				
1	13	0910	34	75	1165
2	13	1137	23	130	671
3	13	1316	33	75	881
4	13	1603	33	80	1032
5	13	1756	32	110	919
6	14	1440	23	80	531
7	14	1237	33	225	756
8	14	1009	33	100	705
9	15	1134	37	225	756
0	15	1344	25	63	328
11	15	1540	27	38	672
12	15	1736	26	45	708
13	20	0804	13	88	141[3]
14	20	0952	15	50	189[4]
15	20	1200	42	208	990
16	20	1703	20	50	475
17	21	0922	21	145	548

Appendix 1.--Continued.

Station	Date	Starting time of tow	Duration of tow (min)	Maximum sample depth (m)	Volume of w filtered (
	June				
18	21	1126	25	55	623
19	21	1707	24	75	548
20	22	0835	22	50	526
21	22	1148	39	>300	858
	July				
1	11	0842	24	75	709
2	11	1142	19	120	450
3	11	1344	21	70	676
4	11	1620	29	80	689
5	11	1755	33	95	738
6	12	1422	22	54	358
7	12	1243	32	215	701
8	12	1017	32	125	510
9	13	1134	44	325	821
10	13	1344	19	50	269
11	13	1520	20	54	222
12	13	1702	18	50	302
13	24	1747	20	75	346
14	25	0913	21	50	300
15	25	1057	43	258	776
16	25	1631	21	50	452
17	25	1825	20	133	434
18	26	0831	21	54	380

Appendix 1.--Continued.

Station	Date	Starting time of tow	Duration of tow (min)	Maximum sample depth (m)	Volume of water filtered (m^3)
	July				
19	26	1416	22	42	491
	26	1522	20	50	441
21	27	1103	43	350	593
	Aug.				
1	15	0841	29	140	584
	15	1142	28	110	687
	15	1421	25	88	467[1]
5	15	1555	30	80	588
	16	1440	23	51	533
7	16	1300	27	182	622
	16	1030	24	95	628
9	17	1151	43	347	1959
	17	1400	18	49	323
11	17	1600	18	47	227
12	17	1738	19	51	345
	21	1755	18	88	294
14	22	0905	21	56	343[1]
	22	1125	34	250	563
16	22	1830	24	63	158
	22	1632	20	151	397
18	23	0910	23	60	325
	23	1500	23	57	436
20	23	1630	24	59	373
21	24	1100	42	297	749

Appendix 1.--Continued.

Station	Date	Starting time of tow	Duration of tow (min)	Maximum sample depth (m)	Volume of wa filtered (m^3)
	Sept.				
1	12	0830	29	96	858
3	12	1120	13	>100	344
4	12	1350	23	72	585
5	12	1520	20	96	446
9	14	1250	35	296	997
10	14	1430	17	48	228
11	14	1600	15	56	156
12	14	1730	15	45	199
13	18	1645	18	72	321
14	19	0955	19	64	485
15	19	1035	38	176	1103[5/]
16	19	1630	20	80	382
17	19	1510	17	148	397
18	20	0915	22	80	534
19	20	1520	23	60	515
20	20	1640	18	50	315
	Oct.				
4	10	1830	21	80	619
6	11	1555	21	56	564
7	10	1330	34	240	799
9	12	1130	35	300	717
10	12	1320	24	48	502
11	12	1450	24	48	490

Appendix 1.--Continued

Station	Date	Starting time of tow	Duration of tow (min)	Maximum sample depth (m)	Volume of water filtered (m^3)
	Oct.				
12	12	1700	24	34	765
13	16	1750	23	72	481
14	17	1000	26	56	621
15	17	1120	32	224	823
16	17	1720	19	58	458
17	17	1530	19	150	417
18	18	0915	26	56	736
19	18	1430	30	88	870
20	18	1615	22	56	498
21	19	1120	40	260	1051
	Nov.				
6	14	1500	22	52	673
7	14	1301	35	261	782
8	14	1640	23	80	688
9	15	1305	44	310	1087
10	16	1025	22	56	641
11	16	1215	23	60	582
12	16	1435	23	52	596

---

[1] The net hit bottom; the sample was discarded.

[2] Greater than 3,000 ml of phytoplankton; sample was discarded.

[3] Greater than 2,800 ml of phytoplankton; sample was discarded.

[4] Greater than 2,000 ml of phytoplankton; sample was discarded.

[5] Because of trash on the surface, the sample could not be processed.

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Estimated Average Daily Instantaneous Numbers of Recreational and Commercial Fishermen and Boaters in the St. Andrew Bay System, Florida, and Adjacent Coastal Waters, 1973

Doyle F. Sutherland

May 1978

U.S. DEPARTMENT OF COMMERCE
Juanita M. Kreps, Secretary
National Oceanic and Atmospheric Administration
Richard A. Frank, Administrator
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Estimated Average Daily Instantaneous Numbers of Recreational and Commercial Fishermen and Boaters in the St. Andrew Bay System, Florida, and Adjacent Coastal Waters, 1973

DOYLE F. SUTHERLAND[1]

ABSTRACT

In the St. Andrew Bay system and adjacent coastal waters, 92.0% of the estimated recreational fishing effort was for finfish, 3.7% for crabs, 2.7% for scallops, 1.4% for oysters, and 0.2% for shrimp. Coastal waters were the most used area for finfish fishing (36.2%), followed by St. Andrew Bay (31.8%), North and West Bays (21.6%), and East Bay (10.4%). Of the estimated effort, 43.5% was from fixed platforms extending over water, 30.8% from private boats, and the remaining 25.7% from shoreline platforms, charter boats, and water. The most popular method of finfish fishing was with a rod and reel (93.9%).

The annual number of daytime anglers was estimated to range from 208,400 to 303,200 with associated expenditures ranging from $4.2 to $6.1 million. The estimates are based on the number of anglers actually seen fishing. The number of transit anglers and other recreational fishermen probably equal or exceed the basic estimates. The average daily instantaneous number of occupants of transit motorboats alone was estimated to reach 52 in North and West Bays, 32 in East Bay, 392 in St. Andrew Bay, and 207 in coastal waters.

The distribution of commercial fishing effort among fisheries was estimated to be 34.7% for shrimp, 33.3% for oysters, 22.0% for finfish, 8.9% for scallops, and 1.1% for crabs. The principal area for each fishery was: East Bay for shrimp (36.5%), oysters (85.7%), and crabs (85.2%); coastal waters for finfish (44.1%); and St. Andrew Bay for scallops (84.4%). The highest estimated average daily instantaneous number of active and transit commercial fishermen in each fishery was 66 for shrimp, 37 for oysters, 91 for finfish, 19 for scallops, and 7 for crabs.

INTRODUCTION

creational fishing, boating, water skiing, snorkeling, scuba diving, and similar activities attract millions of persons to marine and estuarine waters each year. The and for recreational space increases as the popula- grows and leisure time lengthens. Maintenance of the aesthetic values and biological productivity of the coastal zone, consequently, becomes more difficult.

st quantities of living resources are harvested annually by fishermen. Many are occasional fishermen; others are incessant; some fish for sport, others for food, still others for combinations of sport, food, and omic gains. Few game and food fishes escape their attention. Many edible invertebrates also are harvested.

Data on recreational fishing in marine waters are rally unavailable or inadequate for mangement conations. Commercial fisheries, however, are well documented annually, nationwide. Estimates of saltwater angling effort and catch are sparse, although such were obtained in 1960, 1965, and 1970 by the Bureau nsus for the Bureau of Sport Fisheries and Wildlife and the National Marine Fisheries Service (Clark 1962; Deuel and Clark 1968; Deuel 1973). Estimates of saltwater angling effort for specific areas have been made by Richards (1962), Moe (1963), Miller and Gotshall (1965), and Pinkas et al. (1967). Attempts to assess the value of recreational angling for State and local areas have been made by Ellis et al. (1958), Brown et al. (1964), Gilbert and Nobe (1969, cited by Gordon et al. 1973), and Gordon et al. (1973).

This report presents the results of a 1-yr study undertaken to: 1) provide resource managers with comparative statistics on recreational and commercial fishing effort in the St. Andrew Bay system and adjacent coastal waters; 2) determine the socioeconomic value of this area to recreational and commercial fishermen; and 3) contribute to the development of methods for obtaining useful statistics on recreational fishing in the coastal zone. The term effort as used in this paper is defined as the number of fishermen and persons that were counted or estimated.

STUDY AREA

The study area was limited to the St. Andrew Bay system and adjacent coatal waters (Fig. 1) located in Bay

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[1] ama City Laboratory, Southeast Fisheries Center, National Marine es Service, NOAA, Panama City, FL 32401.

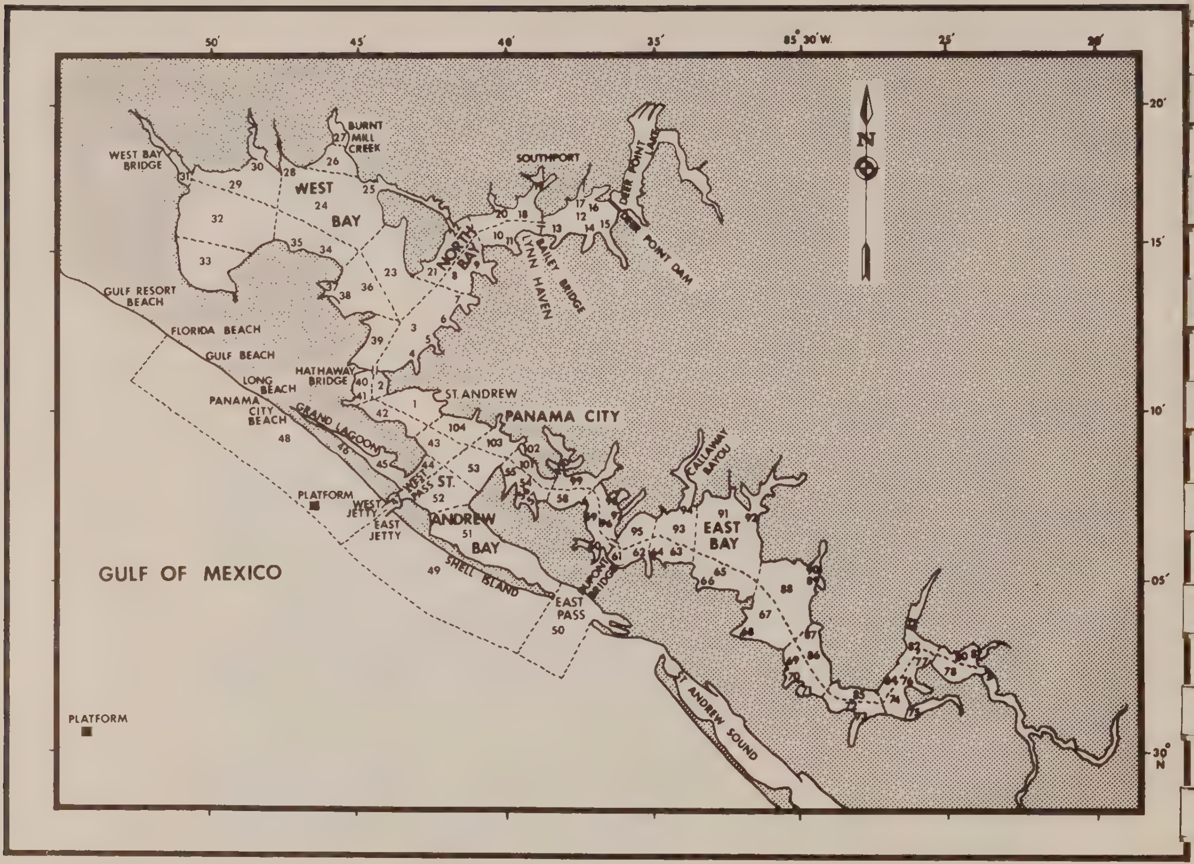

50'
45'
40'
35'
85° 30' W.
25'
20'
20'
15'
10'
05'
30° N
N
WEST BAY BRIDGE
BURNT MILL CREEK
SOUTHPORT
DEER POINT LAKE
DEER POINT DAM
WEST BAY
NORTH BAY
LYNN HAVEN
BAILEY BRIDGE
GULF RESORT BEACH
FLORIDA BEACH
GULF BEACH
LONG BEACH
HATHAWAY BRIDGE
PANAMA CITY BEACH
ST. ANDREW
PANAMA CITY
GRAND LAGOON
CALLAWAY BAYOU
EAST BAY
WEST PASS
ST. ANDREW BAY
PLATFORM
WEST JETTY
EAST JETTY
SHELL ISLAND
EAST PASS
DUPONT BRIDGE
ST. ANDREW SOUND
GULF OF MEXICO
PLATFORM

Figure 1.—Survey area and numbered subareas of the St. Andrew Bay system, Fla., and adjacent coastal waters.

County, Fla., along the northeastern Gulf of Mexico (long. 85°23′ to 85°53′W, lat. 30°00′ to 30°20′N). The system is a shallow plain estuary of about 90 square miles (233 km^2). It consists of North Bay, West Bay, East Bay, and St. Andrew Bay. Two passes (East Pass, a natural channel, and West Pass, an excavated channel) connect St. Andrew Bay to the Gulf of Mexico.

For statistical and logistical reasons the study area was divided into four major areas and each major area into several subareas. The major areas were: 1) North and West Bays, 2) East Bay, 3) St. Andrew Bay, and 4) coastal waters. All bayous and brackish water creeks were included in the areas that could be navigated by outboard motorboat or surveyed from an outboard motorboat with the aid of binoculars.

MARINE ESTUARINE FEATURES

The St. Andrew Bay system was described by Waller (1961) as a positive estuary, in that freshwater inflow exceeds evaporation. Econfina Creek, which is dammed at Deer Point in West Bay, is the principal source of freshwater in the system. Several small creeks contribute to the total inflow. The inland bays are generally less saline than the coastal bay. St. Andrew Bay salinity a proaches that of the Gulf of Mexico waters (hereaft referred as gulf waters) (Hopkins 1964). That salinity and turbidity are related was also revealed by Hopkins (1964); the lower saline waters of the inland bays ha the highest turbidity. Waller (1961) found low salinities and transparencies on the westward side of the bay system. Ichiye (in Waller 1961) suggested the co dition may result from the Coriolis effect. Repeated o servations have shown that gulf waters are usually le transparent west of West Pass than to the east. Floating vegetation of estuarine and freshwater origin is frequen ly seen off West Pass and seldom off East Pass, su gesting that most of the freshwater flows out of the system through West Pass.

The bay system has mean depths of 1.8 m in Nor Bay, 2.1 m in West Bay, 2.1 m in East Bay, and 5.2 m St. Andrew Bay (Waller 1961). Maximan depths to about 15 m are found in ship channels in West Pass and St. Andrew Bay and in the intracoastal waterway through Eas St. Andrew, and West Bays (National Ocean Surve Nautical Chart 868-5C).

East Pass is not maintained, hence it is comparativel shallow and has a constantly shifting entrance chann ye and Jones (1961) estimated 65-75% of the tidal volume flows through this pass.

Except for the maintained ship channel in West Pass seaward approach, the gulf shelf off St. Andrew Bay s es gradually and smoothly from the shore seaward. At the outer limit of the survey area, the water depth ages 18-20 m.

tensive beds of submerged vegetation, primarily *Thalassia* and *Diplanthera*, are found in shallow waters of the bay system and in East Pass. Only small scattered are evident in West Pass and in coastal waters.

onthly average water temperatures of the bay range from 11.5°C in January to 28.8°C in July-August (Hopkins 1964). Mean annual rainfall near Panama City was cm and the mean air temperature was 20.6°C for s 1924-46 (Tyndall Air Force Base, unpubl. manuscr.)

PLANS AND PROCEDURES

This study possibly represents the first attempt to e estimates of all daytime recreational and com ial fishermen and boaters in an estuarine system and adjoining marine waters. Schemes of stratified random sampling and measures of average fishing time have used successfully to estimate total effort in other es (Ellis et al. 1958; Pinkas et al. 1967; Deuel 1973). Such schemes could not be used in this study for the following reasons: 1) reliable estimates of total effort re an intensive survey; 2) all types of fisheries, platforms, and methods of fishing were not known at the beginning of the survey; and 3) the peculiarities of each n fishery precluded randomization of the survey ef vithin areas by fishery or other strata.

To accomplish the stated objectives of this study, the survey was designed to obtain reliable estimates of the ge daily instantaneous fishing effort and boating ity in the four major areas. To facilitate comparison of that effort and activity, the four major areas were surveyed systematically on the same days within a fixed d. For logistic reasons, each major area was sub ed into several subareas (Fig. 1).

The plan was to survey the study area on a weekday and weekend-day each week of 1973. Since the surveys done in small boats, fair weather days were usually selected; most were done in midweekdays and on Saturdays. Time of day, day of the week, starting point, and tion of travel were recognized as unmeasured es of variation affecting the effort estimates. Of the 104 scheduled surveys, 93 were completed and 11 were abandoned owing to adverse weather or motor failure. ffect was to reduce the number of surveys for com g daily average numbers.

The estimated daily averages were computed from actual counts of the observed effort and activity. Counted 1) fishermen and persons participating in each fishery by platform and method of fishing; 2) fishing boats that were used in each fishery; 3) occupants of it boats; and 4) type of transit boat. The term men refers to those individuals actively fishing or have fishing equipment in possession; persons refers to all individuals on a fishing platform including fishermen; occupants refers only to individuals on transit boats that may or may not include fishermen; and transit boats refers to those being launched, hauled, underway, anchored, beached, or moored away from their home docks but not being used as a fishing platform when observed.

Counts were made by the surveyors in single traverses of each subarea. In most subareas, the task was completed in a few minutes; the coastal subareas and other heavily used subareas regularly required from 10 to 60 min to complete. All counts regardless of the time of day or duration were assumed to be estimates of the "instantaneous" numbers of persons in all subareas during the survey day—0800-1630 h.

The four major areas were surveyed by three persons—one assigned to North and West Bays, one to East Bay, and one to St. Andrew Bay and adjacent coastal waters. Each surveyor was equipped with an outboard motorboat, a navigation chart of the area and subareas, 7 × 50 binoculars, fishing effort survey logs, and a fishing effort survey guide. The guide contained a numberically coded list of fisheries, platforms, and methods of fishing that were known or suspected to exist in the study area. Corrections and additions to the list were made when revealed by the survey. This list is shown below as it existed at the end of the survey.

Fishery	*Platform*	*Method*
Fishfish—food, sport or bait	Private boat	Rod and reel—still
Shrimp—food or bait	Commercial boat	Rob and reel—cast
Crab—food or bait	Party boat	Rob and reel—troll
Oyster—food	Charter boat	Canepole or hand-line
Scallop—food	Bridge	Cast net
	Pier	Hands
	Dock	Tongs or rakes
	Jetty	Spear
	Shore	Seine
	Seawall	Trotline
	Abutment	Trap
	Water—wade	Trawl
	Water—swim	Gill net
		Dip net
		Dredge
		Scuba
		Snorkel

On entering each assigned subarea, the surveyor logged the subarea number, time and code numbers of the fisheries, appropriate platforms, and methods of fishing. All fishermen and persons on stationary platforms were counted. In some subareas within major areas, boats were occasionally too numerous or widely dispersed to classify and to count all individuals onboard. Instead, a count of fishermen, persons, or occupants was made for a sample of boats in each fishery or activity and the average per boat expanded by the total number of boats in each classification.

Fishermen and total number of persons on fishing boats or transit boats were particularly difficult to assess owing to concealment by the cabin structure. Number, mobility, and distribution of the boats added to the difficulty. The effort could usually be classified rapidly and accurately by observing the fishing gear, activity of individuals on the boats, movement of the boat, and awareness of the fisheries in the subareas. Close approach and prolonged observation was necessary in cases where an unusual activity was observed or when a single boat was used for more than one fishery.

The effort on fixed platforms also presented problems of classification and assessment. Activity on those platforms was rarely static. Fishermen often changed locations and methods of fishing, left their gear unattended, fished only when fish were sighted, and engaged in two or more fisheries simultaneously. Presence of a large number of persons not fishing further complicated the problem. To minimize the error of assessment, the survey was done in the shortest possible time consistent with good judgment. When the effort was highly concentrated, a total count of all persons on the platform was obtained, followed by a count of the fishermen by fishery and method. Persons moving about, entering or leaving with fishing gear in possession, were classified as fishermen. Some error in classification undoubtedly resulted. For example, handlines used by anglers may have appeared identical to the lines used by crabbers; a fish stringer may have appeared as either; a crab trap may have been set and retrieved by rod and reel; and several persons may have shared fishing equipment.

Snorkel and scuba divers engage in diverse recreational activity. In the coastal area it is a popular method of fishing for finfish. Because time or circumstance did not permit personal interviews, they were arbitrarily included in the count of persons using water as the platform in the finfish fishery. In St. Andrew Bay, snorkel and scuba gear are frequently used by recreational and commercial fishermen in their search for scallops. The fishery, however, was easily identified, and the method of gathering scallops was the same as used by others, i.e., hand or dip net.

METHODS OF ESTIMATING EFFORT

Average Daily Instantaneous Effort

Estimates of the average daily instantaneous fishing effort and boating activity were derived by dividing the number of monthly surveys into the sum of the instantaneous counts or estimates in all subareas each month. Estimated averages were calculated for weekdays and weekend-days each month by fishery, platform, method of fishing, and type of boat within each major area.

In those instances when it was necessary to estimate the number of fishermen, persons, or occupants on boats in a subarea the following formula was used:

$$\bar{x} = \left(\frac{A}{B}\right)C$$

where $\bar{x}$ = estimated number
A = number of fishermen, persons, or occupants in sample
B = number of boats in sample
C = total number of boats.

No attempt was made to count or estimate the number of fishermen on party boats (also called head boats) a those boats did not fish in the study area. Fishermen o private boats when still or cast fishing were identified and counted separately from the total number of persons on board. All persons on trolling boats were counte as fishermen. The distinction between methods of fishing is that still and cast fishing is usually an individual effort, and trolling is often a collective effort. All person on commercial boats, excluding party boats, also wer counted as fishermen. Boats were considered the principal platform when used to reach a secondary platform such as a bridge or shore. When used for snorkeling c scuba diving for finfish, water was considered the principal platform. Persons snorkeling or scuba diving from boats often could not be distinguished from those entering the water from shore.

The estimates of effort were summarized for a stationary platforms, and grouped into three categories as follows: 1) extension (bridge, pier, dock, jetty); 2 shoreline (shore, abutment, seawall); and 3) wate (wade, swim).

Total Daytime Angling Effort

Estimates of the maximum, minimum, and averag number of anglers for the 0800-1630 period were derive from expanded average daily instantaneous numbers. The expansion factors used for anglers and persons on private and charter boats were taken from the results of survey of sport fishing in Virginia by Richard (1962). I that survey, instantaneous counts were made at 2-h intervals from a single observation point and the corrected totals from dockside interviews. Maximum and minimum variations in the instantaneous counts of privat boats yielded corrected total counts when expanded by factors of 2.79 and 1.83, respectively. The average expansion factor was 2.31. For charter boats the expansion factors were 2.18 for maximum estimation, 1.52 for minimum estimation, and 1.80 for average estimation.

Estimates of daytime angling effort on fixed platforms were computed by methods analagous to private an charter boats. Interval counts and interviews were mad at three locations in the St. Andrew Bay system and coastal waters at 2-h intervals twice monthly. Variations in angler effort are shown in Table 1. Since th average fishing time on those platforms was less than 2 h, those anglers who arrived after a surveyor's visit and left before the surveyor's next visit were not counted. Thus the estimated total number of anglers exceeded the sur of interval counts. The estimated total was computed by the method of Moyle and Franklin (1957). The expansion factors derived from the instantaneous counts an ble 1.--Number of anglers counted bihourly, number of anglers interviewed, and total hours fished at three locations in St. Andrew Bay system, Florida, and adjacent coastal waters, 1973.

ation	Time of counts				Anglers interviewed	
	0900	1100	1300	1500	Number	Hours fished
t Jetty	196	409	331	294	298	594.25
Hathaway Bridge	252	323	249	273	234	508.50
r Point Dam	158	144	156	189	180	305.00
al	606	876	736	756	712	1,407.75

e corrected totals were 4.96 for maximum variation, 43 for minimum variation, and 4.4 for average variation.

RECREATIONAL FISHING EFFORT

istribution of Effort

Finfish fishing was by far the most important of the five recreational fisheries that were disclosed by the ef- rt survey (Table 2). Of the sum of the estimated erage daily instantaneous number of recreational fishermen, 92.0% fished for finfish, 3.7% for crabs, 2.7% for scallops, 1.4% for oysters, and 0.2% for shrimp.

Finfish fishing dominated the recreational fishing effort in all areas. Coastal water was the most important single area for finfish fishing (36.2%), closely followed by . Andrew Bay (31.8%). St. Andrew Bay was the most portant for crabbing (64.8%) and scalloping (93.8%), East Bay for oystering (71.8%), and North and West Bays for shrimping (56.3%). While finfish fishing and abbing were important activities in all areas, oystering d shrimping were limited to the bay system and scalloping to St. Andrew Bay and adjacent coastal waters (Table 3).

Finfish Fishing Effort

The estimated recreational finfish fishing effort on weekdays, weekend-days each month in the four major areas is shown in Figure 2. The effort on weekend-days exceeded the weekday effort each month in all areas. The seasonal effort pattern differed by area, however. In North and West Bays and in East Bay, the greatest effort occurred during late fall and winter months, while in St. Andrew Bay and coastal waters it occurred during spring through fall months.

Factors contributing to the differences in seasonal fishing pattern in the four major areas were chiefly environmental conditions, availability of finfish, and vacation schedules. Adverse weather and sea conditions limit boat operations in open bay and coastal waters in late fall through early spring. Pelagic fishes decline in avail-

Table 2.--Percentage distribution of recreational fishing effort among fisheries and areas, 1973.

Fishery	North and West Bays	East Bay	St. Andrew Bay	Coastal waters	Sum
Finfish	19.8	9.6	29.3	33.3	92.0
Crabs	0.8	0.4	2.4	0.1	3.7
Scallops	0.0	0.0	2.6	0.2	2.7
Oysters	0.3	1.0	0.1	0.0	1.4
Shrimp	<0.1	<0.1	<0.1	0.0	0.2

Table 3.--Percentage distribution of recreational fishing effort within fisheries by areas, 1973.

Fishery	North and West Bays	East Bay	St. Andrew Bay	Coastal waters	Sum
Finfish	21.6	10.4	31.8	36.2	100
Crabs	21.9	9.5	64.8	3.8	100
Scallops	0.0	0.0	93.8	6.2	100
Oysters	18.7	71.8	9.5	0.0	100
Shrimp	56.3	19.9	23.8	0.0	100

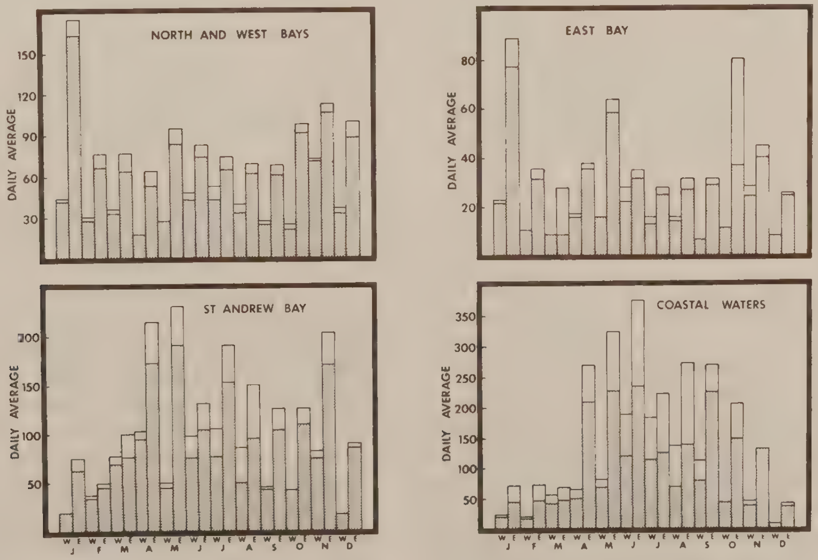


Figure 2.—Estimated average daily instantaneous numbers of recreational finfish fishermen (dark) and persons (light) by areas, weekdays (W), and weekend-days (E) each month in 1973.

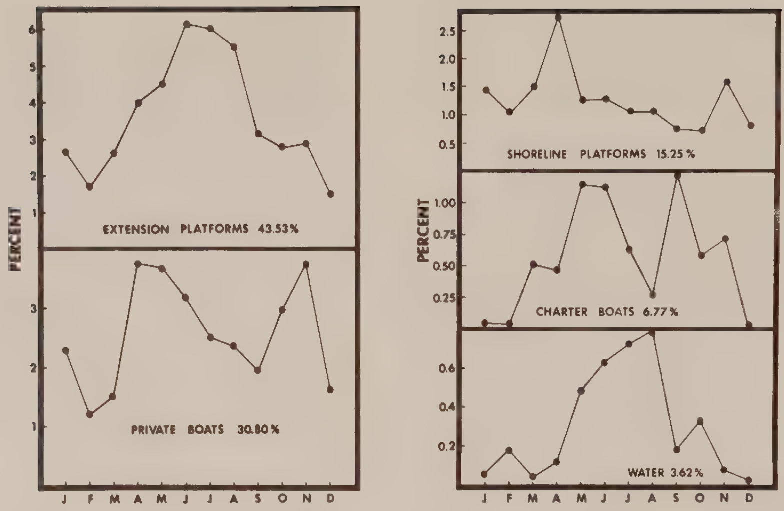


Figure 3.—Percentage distribution of the estimated average daily instantaneous numbers of recreational finfish fishermen in all areas by type of platform used each month in 1973.

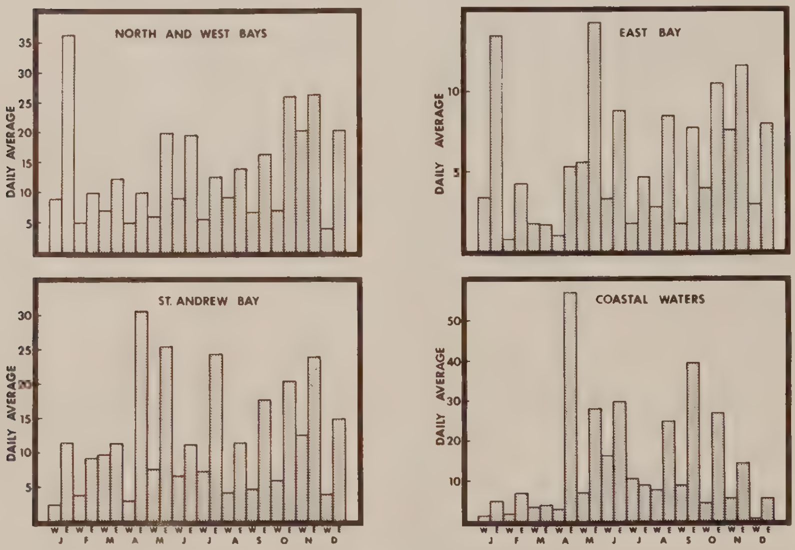


Figure 4.—Estimated average daily instantaneous numbers of private boats used in recreational finfish fishing by areas, weekdays (W), and weekend-days (E) each month in 1973.

ability during these months and certain bay fishes, particularly spotted seatrout, *Cynoscion nebulosus*; red drum, *Sciaenops ocellata*; and mullet, *Mugil* sp., become increasingly available in protected waters. The latter are pursued vigorously by fishermen in small boats and from fixed platforms in lagoons and bayous of the bay areas. Fishing effort in St. Andrews Bay increases in March with the arrival of Spanish mackerel, *Scomberomorus maculatus*, and in coastal waters with the arrival of king mackerel, *Scomberomorus cavalla*, from mid-May to early June. Summer visitors to the area contribute heavily to recreational fishing in St. Andrew Bay and coastal waters.

The percentage distribution of recreational fin fishing effort by type of platform and by month is sho in Figure 3. The sum of all daily estimates of persons finfish fishing was included in the percentage calculati The relative importance of fixed platforms that ext out from the shorelines to other types is clearly indicated. Limitations of the coastal water survey to 2 miles offshore minimizes the relative importance of c ter boats as a fishing platform. Frequently, charter b were seen fishing just beyond the 2-mile boundary during the survey period; many others were observed in transit within the survey area. The limitation also applied private boats, but to a lesser extent.

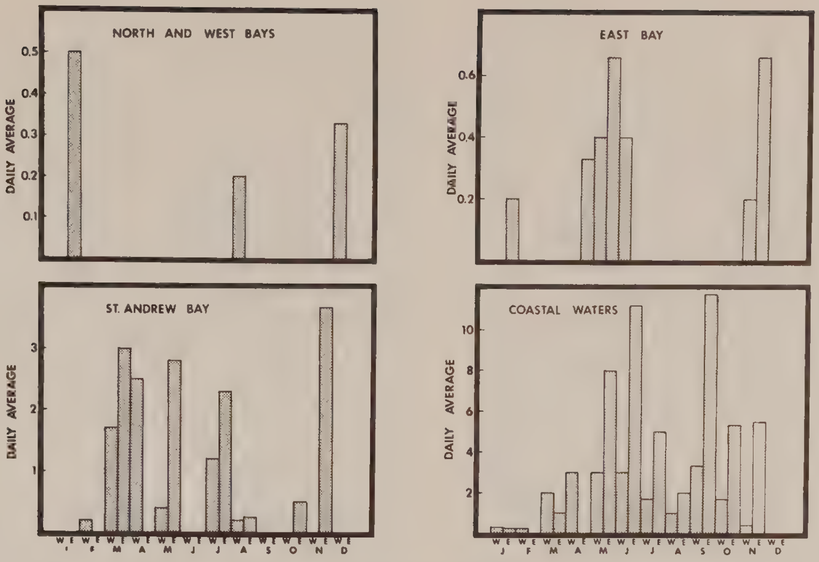


Figure 5.—Estimated average daily instantaneous numbers of charter boats used in recreational finfish fishing by areas, weekdays (W), and weekend-days (E) each month in 1973.

The areal distribution of, and estimated recreational sh fishing effort on, private and charter boats by ths, weekdays, and weekend-days are shown in Figures 4 and 5. All methods of fishing for food, sport, and bait finfish are included in the estimates. The daily monthly variations in distribution and numbers of ate boats were similar to those of finfish fishermen (Fig. 2) for the reasons previously described. In contrast to private boats, charter boats were infrequently seen in h, West, or East Bays. While fishermen occasionally charter a boat to fish in those areas, the relatively small number of fishermen and persons counted on those boats ested that most were used privately by the owner for eational fishing. Seasonal irregularities in the estimated numbers of charter boats in St. Andrew Bay and adjacent coastal waters were largely due to changes in availity and movement of game fishes and to sea conditions. he percentage distribution of recreational finfish fishing effort by method of fishing, area, and platform is shown in Table 4. The percentages were computed from sum of all daily estimates of recreational finfish fishermen and persons snorkeling and scuba diving. Of the various methods of finfish fishing, still, cast, and troll fishing with a rod and reel was by far the most popular, posing 93.9% of the effort in all areas from all platforms. Still fishing with a rod and reel, canepole, and handline composed 61.2% of the effort followed by troll- (22.4%) and casting (12.2%). A substantial number of sons used snorkel and scuba gear in pursuit of finfish (3.2%). Spear (gig) and net fishing composed only 1.0% of the estimated daily effort.

Table 4.--Percentage of distribution of recreational finfish fishing effort by methods of fishing, areas, and platforms in 1973.

Methods	North and West Bays %	East Bay %	St. Andrew Bay %	Coastal waters %	All areas %
			---from private boats---		
RR*-still	65.97	53.97	43.53	25.15	44.99
RR-cast	28.22	35.15	18.05	1.69	17.43
RR-troll	4.60	7.13	37.52	73.08	36.55
Canepole**	0.80	2.30	0.04	0.08	0.52
Spear	0.11	0.12	0	0	0.04
Gillnet	0.11	0.53	0.31	0	0.17
Cast net	0.15	0	0.25	0	0.11
Dip net	0	0.12	0	0	0.01
Seine	0	0.69	0.27	0	0.15
Trotline	0	0	0.04	0	0.01
Trawl	0.04	0	0	0	0.01
			---from charter boats---		
RR-still	34.64	22.07	1.46	0.48	1.08
RR-cast	16.34	65.95	1.12	0	1.25
RR-troll	49.02	7.98	97.42	99.52	97.66
			---from extension platforms---		
RR-still	88.06	90.35	91.41	84.30	87.65
RR-cast	6.32	7.01	3.43	14.44	9.02
Canepole**	4.54	2.01	4.21	1.21	2.77
Cast net	0.95	0.62	0.92	0.05	0.52
Spear	0.13	0	0.04	0	0.04
			---from shoreline platforms---		
RR-still	81.36	72.48	79.77	80.04	79.46
RR-cast	9.28	23.77	12.09	19.96	12.71
Canepole**	5.49	2.60	6.97	0	5.87
Cast net	3.86	1.15	1.17	0	1.97
			---from water---		
RR-still	17.96	20.47	17.54	3.35	8.66
RR-cast	27.89	57.69	26.39	0.65	11.32
Canepole*	0	0	0.25	0	0.07
Spear	4.78	4.60	0	0	0.36
Cast net	27.22	13.65	4.18	1.30	3.58
Gill net	8.79	0	0	0	0.33
Seine	13.37	3.64	7.74	0	2.87
Snorkel	0	0	11.63	64.65	44.42
SCUBA	0	0	32.28	30.04	28.40

*Rod and reel
**Includes handlines

Recreational Anglers and Expenditures

stimates of the number of recreational anglers in the Andrew Bay system and adjacent coastal waters in 1973 and their expenditures were derived from two sources: first, from an estimate of the total number of daytime anglers in each area by months, weekdays, and weekend-days; second, from an estimate of the monies spent per angler per day.

Results of the 1970 national survey of fishing and hunting (U.S. Fish and Wildlife Service, Bureau of Sport

Fisheries and Wildlife 1972) showed that 9,460,000 saltwater fishermen on all coasts spent $1,224,705,000 for 113,694,000 recreational days. From those data, an average of $129 during the entire year or $10.77 each recreational day was calculated to have been spent by each saltwater fisherman. On the gulf coast each of 2,272,000 fishermen spent an average of $178 during the entire year, or $11.36 per recreational day.

In a 1974 survey of Florida's coastal counties, Fred W. Bell (pers. commun.) found that the expenditures relating to a recreational angling day averaged $21.32. An expenditure of $18.97 per angling day was used in this study to estimate the expenditures of recreational anglers in St. Andrew Bay system and adjacent waters. That figure was derived by reducing $21.32 by 11% to account for the inflationary rate during the period 1973-74.

The term "recreational fishermen" as used by the reference sources above applied to recreational anglers only. The term "angler" as currently used refers only to fishermen who use a hook-and-line to take finfish. Therefore, the average expenditure of $18.97 for an angling day applies only to recreational angling for finfish and not to other methods of finfish fishing or to other fisheries. The estimates of anglers and expenditures presented in this section, then, are based on numbers of finfish fishermen identified as fishing with hook-and-line only.

The estimated annual number of daytime anglers in St. Andrew Bay and adjacent coastal waters in 1973 and their expenditures are summarized in Table 5 by area and angling platform.

The number of daytime anglers in all areas and on all platforms was estimated to range from a minimum of 208,400 to a maximum of 303,200 and the expenditures from a minimum of $4.2 million to a maximum of $6.1 million. The estimates include only those anglers that fished from 0800 to 1630 h. Excluded were an approximately equal number of individuals that were classified as occupants of transit boats, the majority of whom were enroute to or returning to finfish fishing grounds.

Crab Fishing Effort

Recreational crab fishing was second in importance to finfish fishing in the St. Andrew Bay system and adjacent coastal waters, composing 3.7% of the recreational fishing effort. Most crab fishing effort was limited to summer months when the blue crab, *Callinectes sapidus*, was available in shallow water. A small winter fishery for the blue crab was observed in West Bay, subarea 25. The water in that subarea, warmed by the effluent from an electric generating plant, provided a suitable shallow water habitat for the crabs in the winter months. The crab was sought primarily for its food value.

The fiddler crab, *Uca* sp., was observed to be harvested by an occasional recreational angler. The crabs are used locally as bait for catching sheepshead, *Archosargus probatocephalus*, and black drum, *Pogonias cromis*.

The estimated recreational crab fishing effort is shown in Figure 6 for major areas, weekdays, and weekend-days each month in 1973. The estimates include both food and bait crab fishing from all platforms by all methods.

Classification and assessment of fishermen and persons participating in the recreational crab fishery were particularly difficult for the surveyor, for it was not essential that all participants have fishing equipment in possession. That is, fishermen may actively search for crabs by wading or boating in shallow water but do not participate in their capture. Frequently, several crab fishermen share a single dip net or crab trap. In areas where both crabs and scallops were found, the fishermen often engage in the two fisheries simultaneously. Baited traps and handlines usually require less than full attention of fishermen. During periods of inactivity, the fishermen may appear to the surveyor as observers. As a result, the number of fishermen may be underestimated or in some cases the effort incorrectly classified.

Comparison of platforms and the estimated average daily instantaneous number of private boats used in the recreational crab fishery are shown in Figures 7 and 8.

Table 5.--Estimates of the annual number of daytime recreational anglers and expenditures (in hundreds) in St. Andrew Bay system and adjacent coastal waters in 1973 by areas and fishing platforms.

	Areas									
	North and West Bays		East Bay		St. Andrew Bay		Coastal Waters		Total	
Range	Anglers	Dollars	Anglers	Dollars	Anglers	Dollars	Anglers	Dollars	Anglers	Dollars
					Private Boats					
Maximum	250.3	4,997.7	95.6	1,908.9	216.0	4,313.7	275.4	5,499.6	837.3	16,719.9
Minimum	166.4	3,323.4	62.7	1,251.3	148.2	2,959.0	183.8	3,671.5	561.1	11,205.2
Average	207.5	4,144.2	79.2	1,580.8	187.2	3,737.8	230.0	4,593.9	703.9	14,056.7
					Charter Boats					
Maximum	0.4	8.8	2.2	43.3	31.4	627.5	116.6	2,328.5	150.6	3,008.1
Minimum	0.3	6.2	1.5	30.2	21.9	437.7	81.7	1,631.6	105.4	2,105.7
Average	0.4	7.2	1.8	36.2	25.9	518.0	96.8	1,932.3	124.9	2,493.7
					Extension Platforms					
Maximum	258.3	5,158.2	129.8	2,592.9	454.8	9,083.2	638.0	12,741.7	1,480.9	29,576.0
Minimum	178.6	3,567.6	89.8	1,792.3	314.5	6,281.4	441.2	8,810.4	1,024.1	20,451.7
Average	210.4	4,201.1	106.0	2,116.4	370.5	7,398.3	520.6	10,396.6	1,207.5	24,112.4
					Shoreline Platforms					
Maximum	150.8	3,011.7	57.2	1,142.5	303.5	6,060.5	9.2	183.5	520.7	10,398.2
Minimum	104.4	2,085.1	39.6	790.0	213.3	4,259.4	6.4	126.8	363.7	7,261.3
Average	123.0	2,456.1	46.6	931.0	251.2	5,016.9	7.5	149.6	428.3	8,553.6
					Water Platforms					
Maximum	2.9	58.7	4.4	88.7	23.5	469.3	11.7	234.0	42.5	850.7
Minimum	2.0	40.5	3.1	61.5	16.2	324.3	8.1	161.8	29.4	588.1
Average	2.4	47.5	3.6	72.3	19.1	380.8	9.5	190.5	34.6	691.1

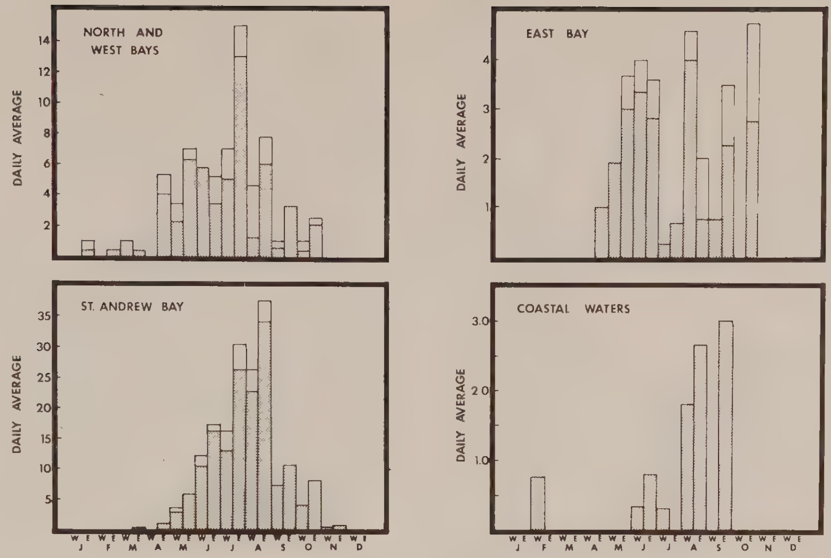
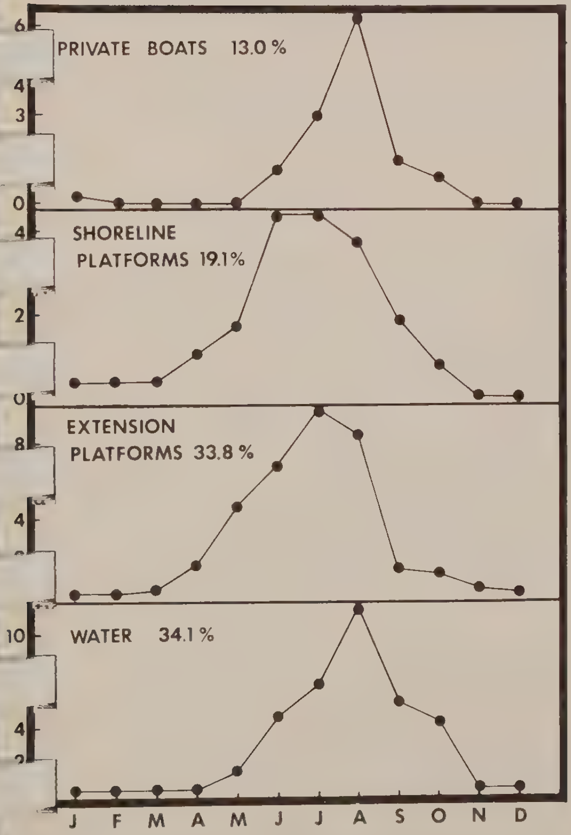


Figure 6.—Estimated average daily instantaneous numbers of recreational crab fishermen (dark) and persons (light) by areas, weekdays (W), and weekend-days (E) each month in 1973.



Fi re 7.—Percentage distribution of the estimated average daily ntaneous numbers of recreational crab fishermen in all areas pe of platform used each month in 1973.

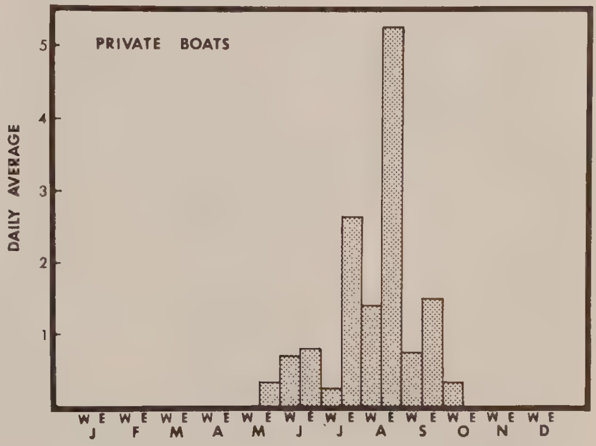


Figure 8.—Estimated average daily instantaneous numbers of private boats used for recreational crab fishing in all areas on weekdays (W) and weekend-days (E) each month in 1973.

Table 6.--Percentage distribution of recreational crab fishing effort by methods of fishing, areas, and platforms in 1973.

Methods	North and West Bays %	East Bay %	St. Andrew Bay %	Coastal waters %	All areas %
			private boats		
Dip net	66.3	100.0	95.2	0	87.9
Trap	27.4	0	4.8	0	10.4
Trotline	6.3	0	0	0	1.7
			extension platforms		
Dip nets	10.9	35.6	1.2	0	4.9
Trap	82.1	12.2	83.4	3.73	79.7
Handline	7.0	52.2	15.4	0	15.4
			shoreline platforms		
Dip net	31.8	60.3	16.1	0	28.1
Trap	38.0	33.4	70.1	0	50.5
Handline	30.2	6.2	13.8	0	21.4
			water		
Dip net	100.0	93.7	99.7	5.16	99.2
Handline	0	6.3	0.3	0	0.8

he order of preference for crab fishing platforms as in- ted by the estimated number of fishermen was water (36.1%), extension platforms (34.1%), shoreline platforms (17.7%), and private boats (12.1%).

Assessment of the methods of recreational crab fishing by type of platform and month is shown in Table 6.

Crabbers fishing in shallow water by wading or boating preferred to visually search and capture crabs with a dip net (93.6%). Since the crabs frequent shallow water and were widely distributed, availability was virtually assured at all access sites. A trap was preferred by those fishermen on extension and shoreline platforms (65.1%). The crab fishing effort by trapping may be underestimated, however, for many traps are fished almost continuously from private docks.

Scallop Fishing Effort

The bay scallop, *Pecten irradians*, supported a substantial recreational fishery in 1973. That fishery attracted 2.8% of the estimated effort for all fisheries and was third in importance to recreational fishermen after finfish and crabs.

Unlike finfish and crabs, scallops were limited in distribution to lower St. Andrew Bay and East Pass. According to the distribution of fishing effort they were found in abundance only in subareas 44, 45, and 50-53. An occasional scallop fisherman was seen in other subareas of St. Andrew Bay; none were seen in North, West, or East Bay. While scallops apparently reside in gra beds all year (Gutsell 1931), the annual harvest began early May and extended through September. Florida State law permits taking of scallops by hand or dredge from 1 June through 15 October and only by hand other days.

The estimated recreational scallop fishing effort is shown in Figure 9 by areas on weekdays and weekend-days each month in 1973. The estimated effort includ all methods of fishing from all platforms.

Only two platforms were used in this fishery, private boats and water (Figs. 10, 11). Private boats serv primarily as a means of transport to scallop ground Most fishermen entered the water and fished by wading, snorkeling, and scuba diving. Those that used water as the primary platform entered from shore.

Most fishermen preferred to search for scallops a catch them by hand (Table 7). Snorkel and scuba equipment extended the effort to considerable depth. Comparatively few fishermen searched for scallops wh standing in a boat or by wading and dip netting them i manner similar to crab fishing. A dredge was fished occasionally from private motorboats.

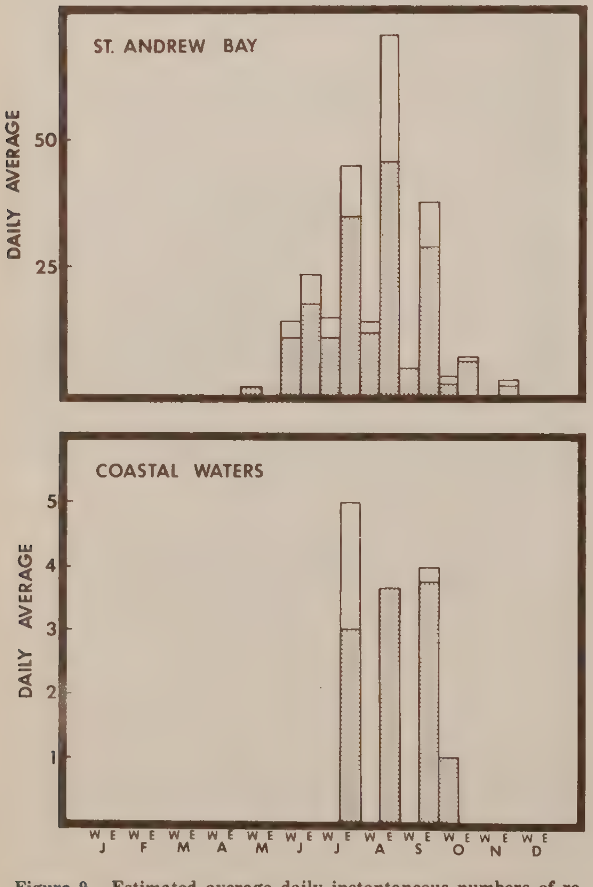


Figure 9.—Estimated average daily instantaneous numbers of recreational scallop fishermen (dark) and persons (light) by areas, weekdays (W), and weekend-days (E) each month in 1973. None was observed in North, West, and East Bays.

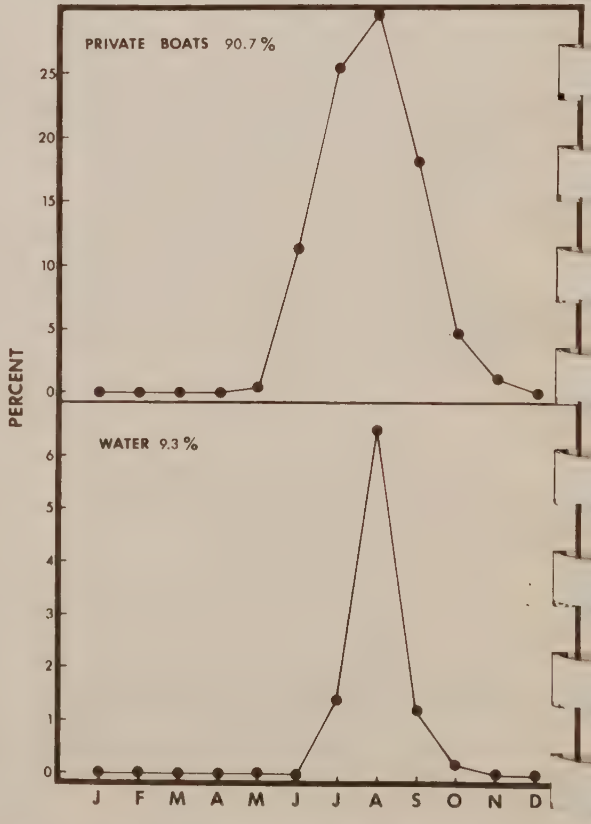
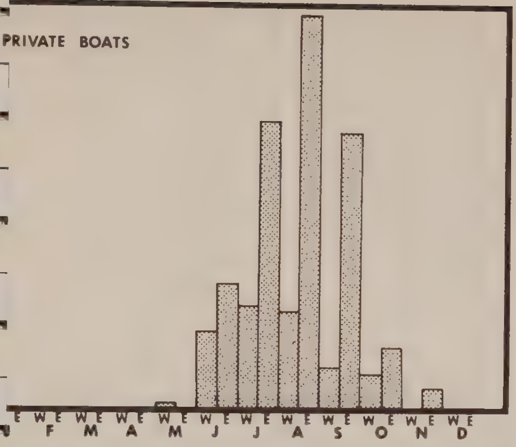


Figure 10.—Percentage distribution of the estimated average daily instantaneous numbers of recreational scallop fishermen in all a by type of platform used each month in 1973.



ure 11.—Estimated average daily instantaneous numbers of pri- ; used for recreational scallop fishing in all areas on week- and weekend-days (E) each month in 1973.

Percentage distribution of recreational scallop fishing effort by methods of fishing, areas, and platforms in 1973.

	Private boats			Water		
	St. Andrew Bay %	Coastal waters %	All areas %	St. Andrew Bay %	Coastal waters %	All areas %
	89.2	26.7	86.0	84.1	100.0	89.1
redge	9.70	73.3	13.0	0	0	0
ip net	1.1	0	1.0	15.9	0	10.9

yster Fishing Effort

yster fishery attracted 1.4% of the estimated creational fishing effort and was fourth in importance recreational fishermen after finfish, crabs, and Of that effort, 71.8% occurred in East Bay, North and West Bays, and 9.5% in St. Andrew y. None occurred in coastal waters.

In East Bay, subareas 92 and 94 supported most of the g effort, although numerous oyster beds are ated in the bay and in most bayous. Subarea 12 and joining bayous, subarea 19 and adjoining bay area, area 30 and adjoining bay area were popular oys- inds in North and West Bays. Virtually all creational oystering in St. Andrew Bay was observed in bareas 59 and 60.

stimated recreational oyster fishing effort is n Figure 12 by areas, weekdays, and weekend- ys each month in 1973. The taking of oysters is ohibited by law in June, July, and August.

r fishing was done primarily from private boats ore productive beds were inaccessible from fixed tforms. During periods of very low tide, exposed oys- e harvested in limited numbers from shore or by Assessment of the recreational oystering effort type of platform is shown in Figure 13 and the num- r of private boats in Figure 14.

of the oysters were harvested with tongs or rakes ts anchored over oyster beds (Table 8). In shallow water and intertidal zone the oysters were simply gathered by hand or dip net.

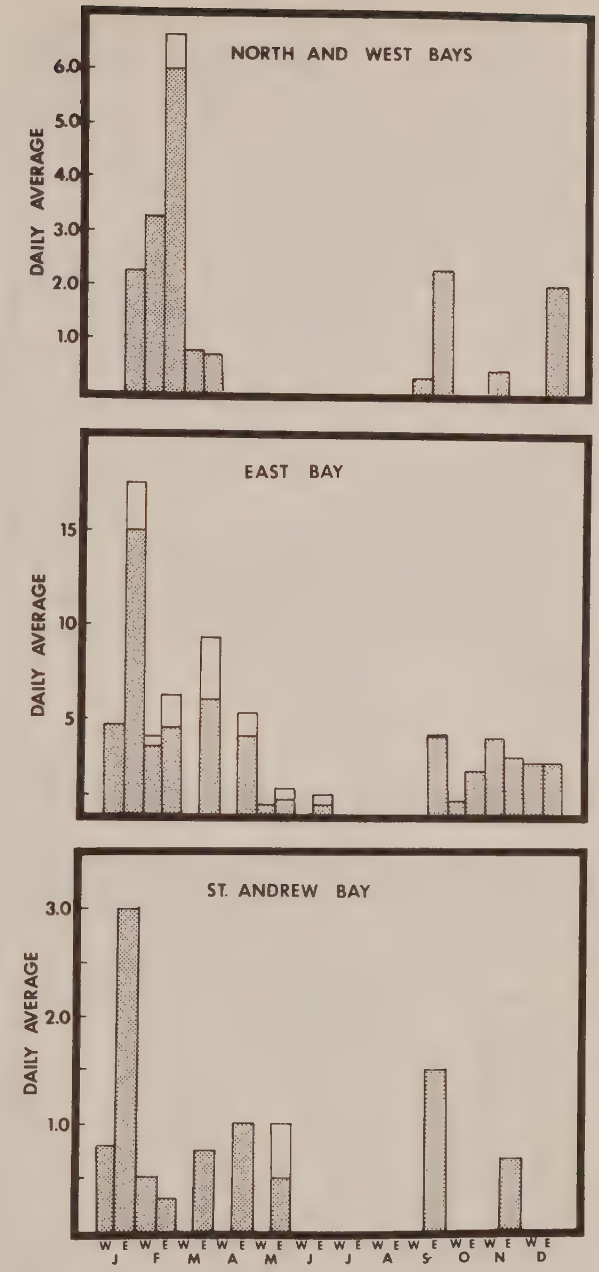


Figure 12.—Estimated average daily instantaneous numbers of recreational oyster fishermen (dark) and persons (light) by areas, weekdays (W), and weekend-days (E) each month in 1973. None was observed in coastal waters.

Shrimp Fishing Effort

From the results of this survey, shrimp was ranked fifth and least important of the daytime recreational fisheries in the St. Andrew Bay system and adjacent coastal waters in 1973. That effort, composed 0.2% of the

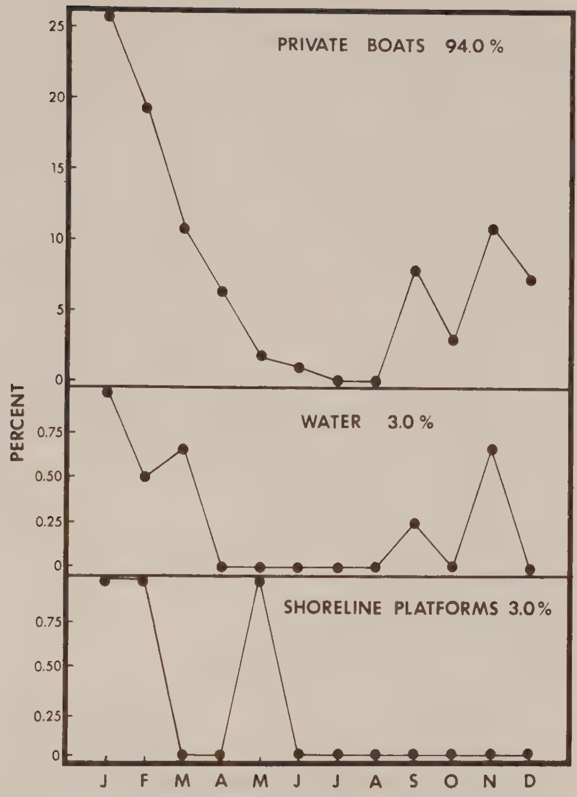


Figure 13.—Percentage distribution of the estimated daily instantaneous numbers of private boats used for recreational scallop fishing in all areas on weekdays (W) and weekend-days (E) each month in 1973.

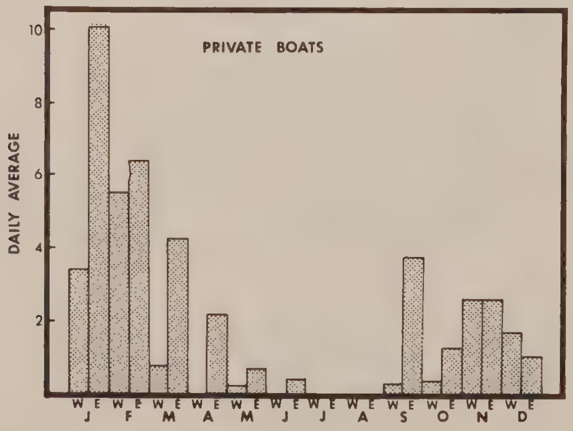


Figure 14.—Estimated average daily instantaneous numbers of private boats used for recreational scallop fishing in all areas on weekdays (W) and weekend-days (E) each month in 1973.

estimated effort for all fisheries, was irregularly distributed through the year and was essentially limited to weekend-days in North and West Bays (Fig. 15).

Table 8.--Percentage distribution of recreational oyster fishing
methods of fishing, areas, and platforms in 1973.

Methods	North and West Bays %	East Bay %	St. Andrew Bay %	All
Private boats				
Tongs	82.68	93.11	93.63	90.89
Hands	3.87	5.82	6.37	5.45
Dredge	11.55	0	0	2.51
Dip net	1.90	1.07	0	
Shoreline platforms				
Tongs	0	30.00	0	[illegible]
Hands	0	70.00	100.00	90.00
Water				
Tongs	0	47.92	0	
Hands	100.00	52.08	0.67	

The observed recreational shrimping was limited trawling with private boats and trapping from s platforms. The trawling effort could easily be id by the boat rigging and trawl warp. Shrimp trappin however, was a problem as the method differs lit that used by crabbers. By close observation, t veyor could usually detect differences in the trap and a cessories used in the two fisheries. On occasion, the fis ery could only be determined from personal int

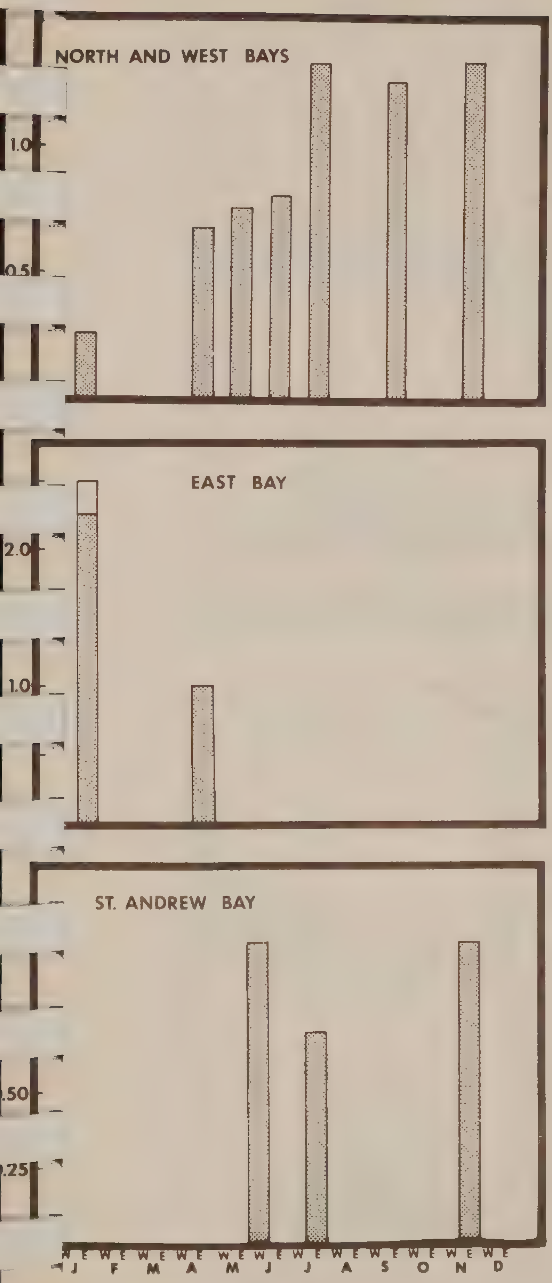
Assessment of the platforms and methods th used in the recreational shrimp fishery is shown Figures 16 and 17 and Table 9.

TRANSIT RECREATIONAL BOAT AND OCCUPANTS

This survey included an assessment of recreational boats and occupants. Since circumstanc did not permit personal interview of the occupants, the activities were simply classed according to bo From repeated observations, the function of mo could be determined from the boat structure, gear, a pearance of the occupants, location, and direction travel. On weekdays and in inclement weather timated 90-100% of the observed private mo were enroute to or returning from fishing. On weeken days during fair weather the proportion of no motorboats increased but probably did not exce

Included in the category of private motorbo licensed and unlicensed boats of all sizes or classes use for recreational purposes, rentals with or without canoes with or without a motor, and motori flatable craft. Nonmotorized rafts, such as inner tub and similar floatation devices, were excluded since th relate more to swimming than fishing. The es average daily instantaneous number of private boats is shown in Figure 18 by areas, weekdays, ar weekend-days for each month in 1973.

Sailing was an important recreational pursuit waters. However, an occasional sailboat was se ing while under full sail. They also served as an anchor platform for finfish fishing, crabbing, and sc Classification and assessment in such cases was t as other private boats. Of the observed sa probably less than 5% were used as fishing platforms. area comparison of the estimated average daily of transit sailboats is shown in Figure 19.



—Estimated average daily instantaneous numbers of re- hrimp fishermen (dark) and persons (light) by areas, V), and weekend-days (E) each month in 1973. None was ved in coastal waters.

like sailing, was an important recreational rt in local waters. Ski boats are commonly used rnately for skiing and fishing. Their proportionate shing platform was not determined by this sur- rea comparison of the estimated average daily of transit ski boats is shown in Figure 20.

rom 125 to 130 charter boats and about 15 party boats intermittently or on a daily schedule out of nas in 1973. They are included in this section

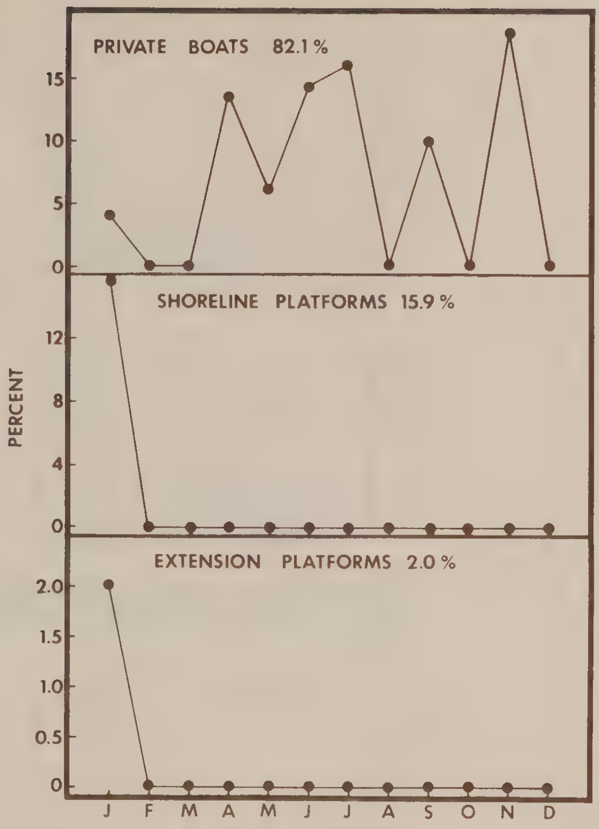


Figure 16.—Percentage distribution of the estimated average daily instantaneous numbers of recreational shrimp fishermen in all areas by type of platform used each month in 1973.

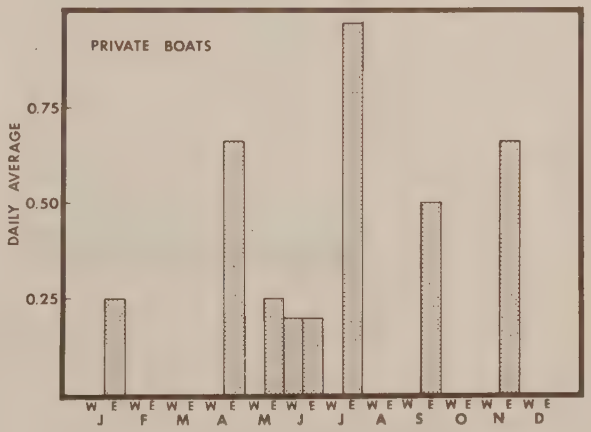


Figure 17.—Estimated average daily instantaneous numbers of private boats used for recreational shrimp fishing in all areas on weekdays (W) and weekend-days (E) each month in 1973.

Table 9.--Percentage distribution of recreational shrimp fishing effort by methods of fishing areas and platforms in 1973.

Method	North and West Bays %	East Bay %	St. Andrew Bay %	Coastal waters %	All areas %
			private boats		
Trawl	96.08	22.22	2.67	0	82.30
			shoreline platforms		
Trap	3.92	77.78	0	0	17.70

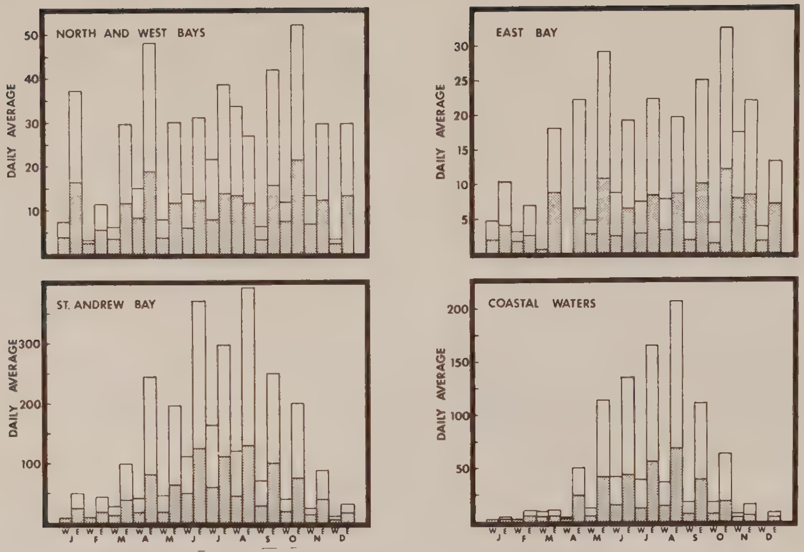


Figure 18.—Estimated average daily instantaneous numbers of transit private motorboats (dark) and occupants (light) by areas, weekdays (W), and weekend-days (E) each month in 1973.

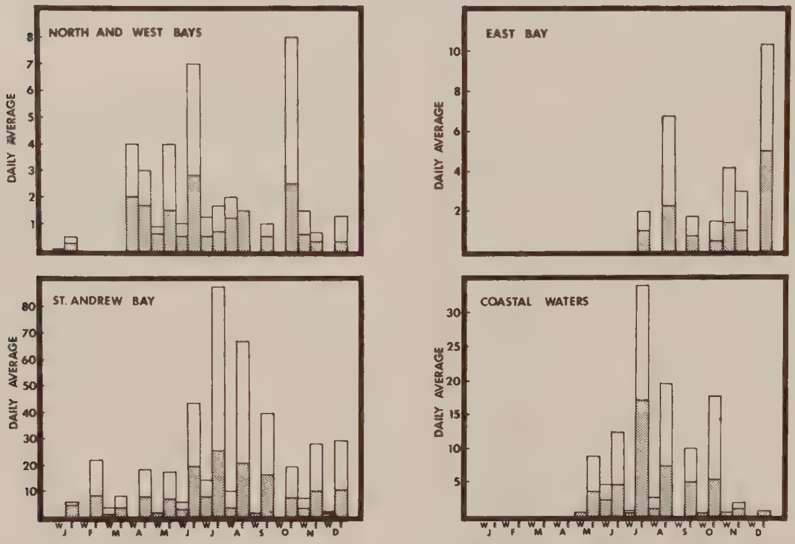


Figure 19.—Estimated average daily instantaneous numbers of transit private sailboats (dark) and occupants (light) by areas, weekdays (W), and weekend-days (E) each month in 1973.

because of their direct participation in recreational finfish fishing, recognizing such boats do, in fact, commercialize recreational fishing. Charter boats are those boats licensed for hire by the U.S. Coast Guard and the captain is licensed to carry passengers for a fee. Generally, fishermen verbally contract the services of the boat and captain. Party boats and captains, also licensed by the U.S. Coast Guard, normally do not operate on a contractual basis. Instead, they charge a fixed fee for passage and services.

Charter boats can usually be identified from a distance by their hull design, rigging, and arrangement of fishing accommodations in the cockpit. Most of the finfish fishing effort by chartered boats was in coas offshore waters. As a result, a substantial part fishing effort was outside the survey area. The estimate number of transit boats and fishermen in St. Andre Bay and coastal waters (Fig. 21) largely reflects tensity of recreatioal fishing effort in offshore

According to the effort survey, party boats were n used as a fishing platform in St. Andrew Bay or coastal waters in 1973. Apparently the numb species of bottom fishes usually sought by the party bo fleet was insufficient to supply the demand. Most of t boats that regularly made daily trips traveled 10- offshore to find fish; a few traveled 40-50 miles

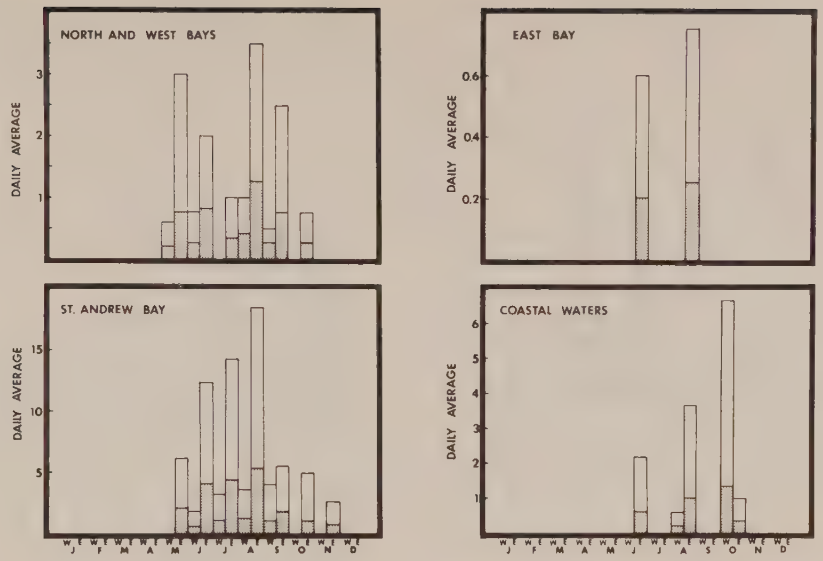


Figure 20.—Estimated average daily instantaneous numbers of transit private ski boats (dark) and occupants (light) by areas, weekdays (W), and weekend-days (E) each month in 1973.

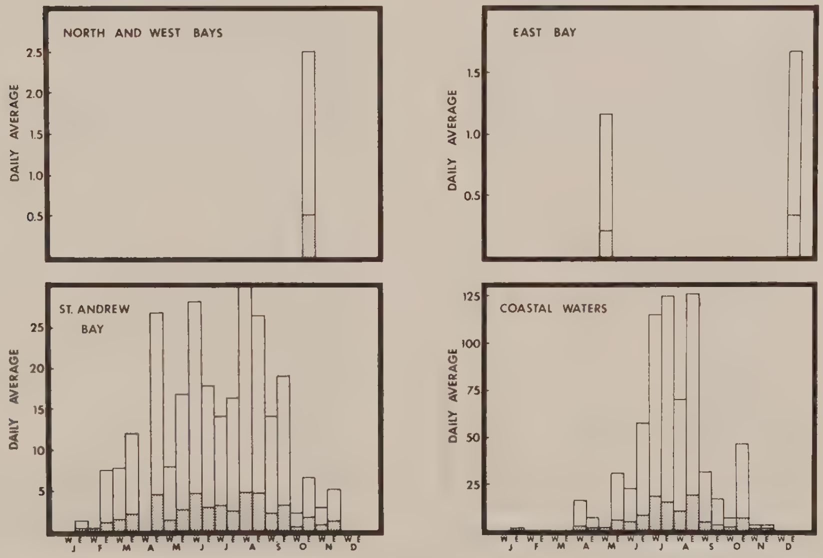


Figure 21.—Estimated daily instantaneous numbers of transit charter boats (dark) and occupants (light) by areas, weekdays (W), and weekend-days (E) each month in 1973.

ch day. The larger party boats are licensed to carry a m of 90 persons, but usually limit the number of n to about 70; a minimum of 15 fishermen is nerally required by the boat operators. The average of fishermen on party boats probably averages er the entire season. At a distance, party boats ay be confused with commercial snapper boats, for the ll design is similar, otherwise there was little dif- ssessing transit party boats. The estimated num- ansit party boats is shown in Figure 22.

COMMERCIAL FISHING

Distribution of Effort

From the results of the survey for commercial fishing effort, five commercial fisheries existed in the St. Andrew Bay system and adjacent coastal waters in 1973. Those fisheries, identical to the ones described under recreational fishing, were: shrimping for food or bait, oystering for food, finfish fishing for food or bait, scalloping

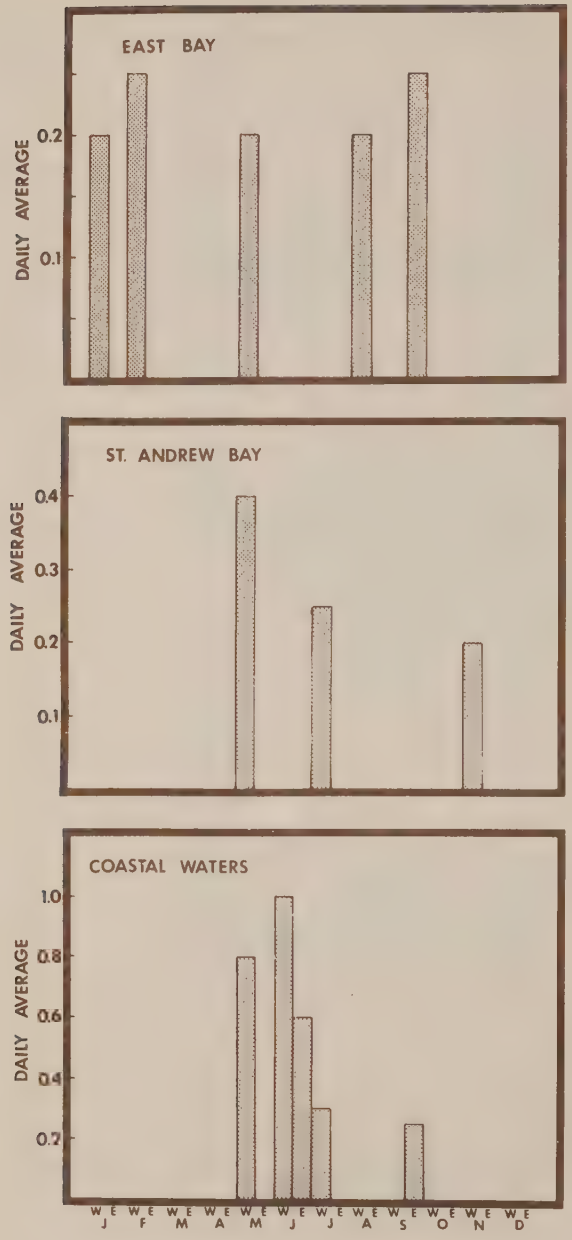


Figure 22.—Estimated average daily instantaneous numbers of transit party boats by areas, weekdays (W), and weekend-days (E) each month in 1973. None was observed in North and West Bays.

Table 10.--Percentage distribution of all commercial fishing effort among fisheries and areas, 1973.

Fishery	North and West Bays	East Bay	St. Andrew Bay	Coastal waters	Total
Shrimp	12.0	12.7	10.0	0.0	34.7
Oysters	4.6	28.5	0.2	0.0	33.3
Finfish	5.6	2.2	4.5	9.7	22.0
Scallops	0.0	0.1	7.5	1.3	8.9
Crabs	<0.1	1.0	<0.1	0.0	1.1

for food, and crabbing for food. The perce age tribution of effort among the fisheries, based on the of all effort estimates was (Table 10): shrim oysters, 33.3%; finfish, 22.0%; scallops, 8.9%; 1.1%.

The area preference for each fishery as indicate the effort estimates was (Table 11): East Bay f (36.5%), oysters (85.7%), and crabs (85.2% waters for finfish (44.1%); and St. Andrew Bay scallops (84.4%).

Shrimp Fishing Effort

Of the five fisheries in the St. Andrew Bay sy adjacent coastal waters revealed by this surve was first in importance to commercial fishermen. Th fort was well distributed throughout the bay sys (Table 11). While no shrimping effort was within the coastal waters, a viable fishery ex offshore of the survey boundary.

Trawlers rigged with either a single or double t fished for shrimp in the bay system. The sin trawler, generally smaller and more maneuvera two, fished from maximum depth to the edge of sha water grass beds, whereas the double rigged traw were generally limited to fishing deep water in the intracoastal waterway and other navigat nels.

The estimated daytime commercial shrimpi shown in Figure 23, is thought to be a relati part of the total shrimping effort in St. Andrew Since shrimp are more vulnerable to trawls fishe night, the major effort undoubtedly occure time. The estimated numbers of transit shri (Fig. 24) partially reflect the intensity of the n fishery. Most of those boats were observed by the veyors during the early morning and late aftern enroute to the docks or returning to the shrin grounds. The estimates of transit shrimp boats in jacent coastal waters are indicative of the night shri ing effort in offshore waters.

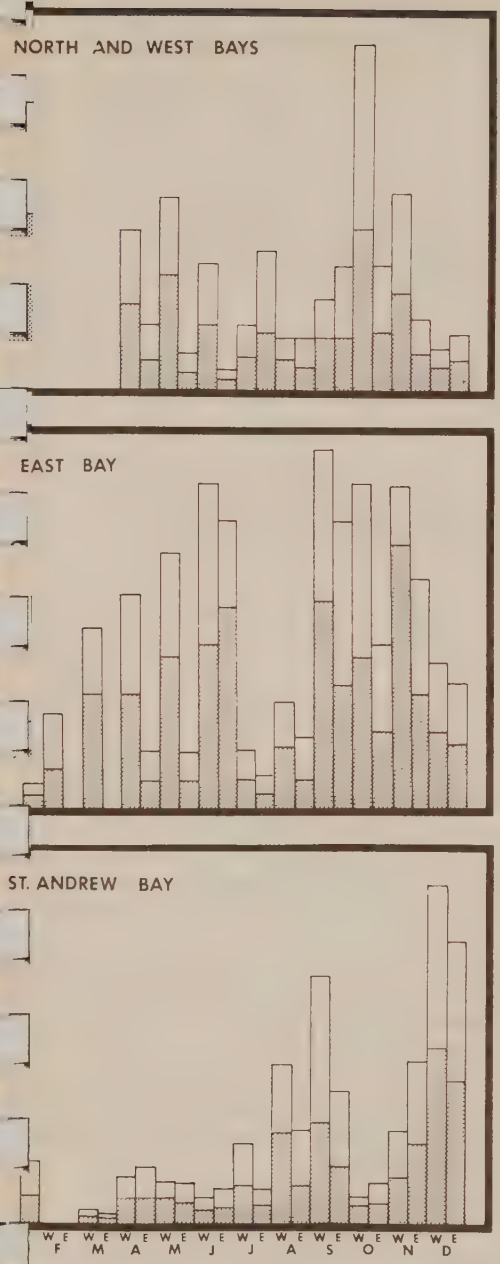
The commercial shrimp fishing effort obser Andrew Bay system was entirely by trawling.

Oyster Fishing Effort

The oyster fishery was second in importance to c mercial fishermen in the study area accounting of the total estimated daily effort expended a

Table 11-- Percentage distribution of commercial fishing effo fisheries by area, 1973.

Fishery	North and West Bays	East Bay	St. Andrew Bay	Coastal waters	To
Shrimp	34.6	36.5	28.9	0.0	
Oyster	13.9	85.7	0.4	0.0	
Finfish	25.5	9.9	20.5	44.1	
Scallop	0.0	1.1	84.4	14.5	
Crab	9.1	85.2	5.7	0.0	



e 23.—Estimated average daily instantaneous numbers of erci shrimp fishermen (light) and boats (dark) by areas,), and weekend-days (E) each month in 1973. None in coastal waters.

Of the oyster fishing effort 85.7% was in East)% in North and West Bays, 0.4% in St. Andrew y, and 0% in coastal waters (Table 11).

he observed oyster fishing effort was essentially o subareas 88, 90, 91, and 92 in East Bay, sub- n North Bay, subarea 29 and 30 in West Bay, d subarea 59 in St. Andrew Bay. Both public and vate beds were harvested by the commercial fisher-

The seasonal pattern and level of oyster fishing effort are shown in Figure 25 and transit boats in Figure 26. In Florida the taking of oysters is prohibited by law during June, July, and August. A small effort during the closed season was revealed in North and West Bays by the survey, however. The level of effort in season probably resulted from several factors including, but not limited to, the price of oysters, their condition (size, quality), and competing opportunities for the fishermen. The availability of scallops in September and October provides the fishermen with an optional fishery. The specially built flat-bottom, wooden boats used in the oyster fishery are also adaptable to the scallop fishery.

The fishermen in the St. Andrew Bay system relied on individually operated oyster tongs as the method of harvesting oysters commercially. The only observed exception was a single commercial fisherman using a dip net to reach oysters in shallow water.

Finfish Fishing Effort

The finfish fishery of the St. Andrew Bay system and adjacent coastal waters was third in importance to commercial fishermen as measured by the estimated fishing effort. That effort amounted to 22.0% of the sum of the estimated effort for all fisheries. By area 44.1% of the effort was in coastal waters, 25.5% in North and West Bays, 20.5% in St. Andrew Bay, and 9.9% in East Bay (Table 11). The daily and monthly estimated number of fishermen and boats engaged in commercial finfish fishing is shown in Figure 27; transit finfish fishermen and boats are shown in Figure 28.

Of the finfish fishing effort, 68.9% was classified as seine fishing for bait and 31.1% as gill net fishing for food fish. Since circumstances did not permit personal interviews or inspection of the catch, the percentage figures may be in error. Most seine boats that operated along the coastal beaches and in the passes carried nets of various mesh sizes for fishing for both bait and food fishes. The target species of that fishery generally were the round scad, *Decapterus punctatus*; scaled sardine, *Harengula pensacolae*; and ladyfish, *Elops saurus*. These species are used extensively as bait by recreational and commercial fishermen. Food fishes, however, were sought when seasonally available; mixed catches of bait and food fishes were common to that fishery.

In the bay system, beach seines were used primarily to catch food fish and secondarily to capture bait fishes. The shallow draft boats especially built to operate along the ocean beaches serve equally well in shallow bay, bayou, and lagoon waters.

All observed gill net fishing was judged to be for food fish, although low-quality food fishes that were caught by gill netters undoubtedly entered the bait fish market. The preferred fishes were chiefly mullet, *Mugil* sp.; spotted seatrout, *Cynoscion nebulosus*; and pompano, *Trachinotus carolinus*. The mullet and seatrout fisheries were essentially limited to late fall and winter, when they become relatively abundant in marketable size. The pompano is generally available from spring to late fall.

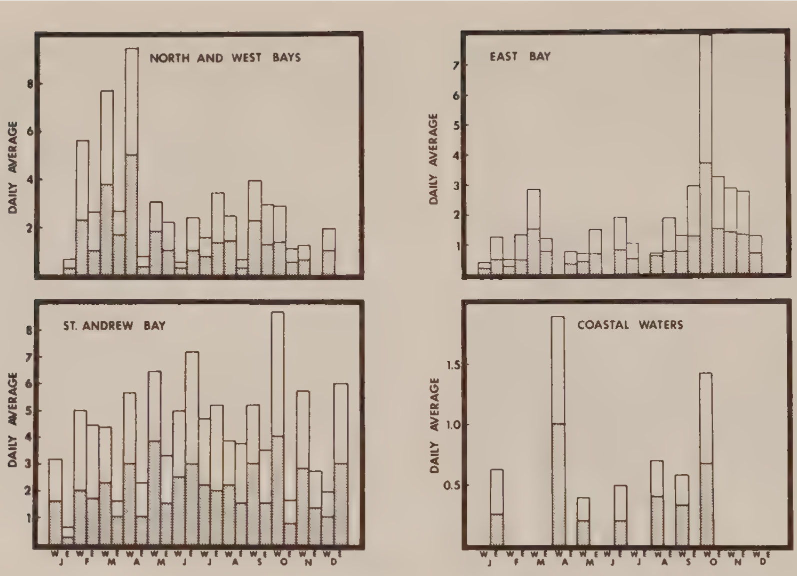


Figure 24.—Estimated average daily instantaneous numbers of transit commercial shrimp fishing boats (dark) and occupants (light) by areas, weekdays (W), and weekend-days (E) each month in 1973.

Since these fishes occur in protected waters of the bay system, they attract the attention of many full- and part-time commercial fishermen, as a comparatively small expenditure for gear or labor is required to participate in the fishery. One- and two-man operations were commonly observed. A similar fishery was described in detail by Irby (1974) for Okaloosa and Walton Counties in northwest Florida.

Commercial Scallop Fishery

The scallop fishery was fourth in importance to commercial fishermen in the area; it accounted for 22.0% of the estimated effort for all fisheries. According to the distribution of effort, scallops occurred in commercial quantity only in lower St. Andrew Bay (subareas 44, 51, 52) and in East Pass (subarea 50). A minor fishing effort with a dredge was observed in East Bay. Since scallops are not known to occur in the East Bay area, the effort possibly was exploratory in nature or misclassified. The latter seems more likely for a limited amount of dredging of leased oyster beds is permitted by the State of Florida.

The estimated numbers of scallop fishermen and boats are shown in Figure 29 for weekdays and weekend-days each month in 1973. The numbers of transit scallop boats and occupants are shown in Figure 30.

The flat-bottom, wooden boat mentioned in the section on commercial oyster fishing also served as the primary platform for scallop fishing. The method most employed to harvest the scallops was to tow a sled-type dredge through the grass beds inhabited by scallops. State laws limit the mechanical harvest of scallop to the period from 15 October to June 1. An occasional commercial fisherman was seen gathering scallops by hand with the aid of scuba gear.

Commercial Crab Fishing

Commercial crabbing was ranked fifth and lea important among the commercial fisheries in the areas measured by fishing effort. That effort involv 1.2% of the sum of the estimated effort for t fisheries. By area 85.2% of the crabbing effort was in Ea Bay, 9.1% in North and West Bays, 5.7% in St. Andre Bay, and 0.0% in coastal waters (Table 11).

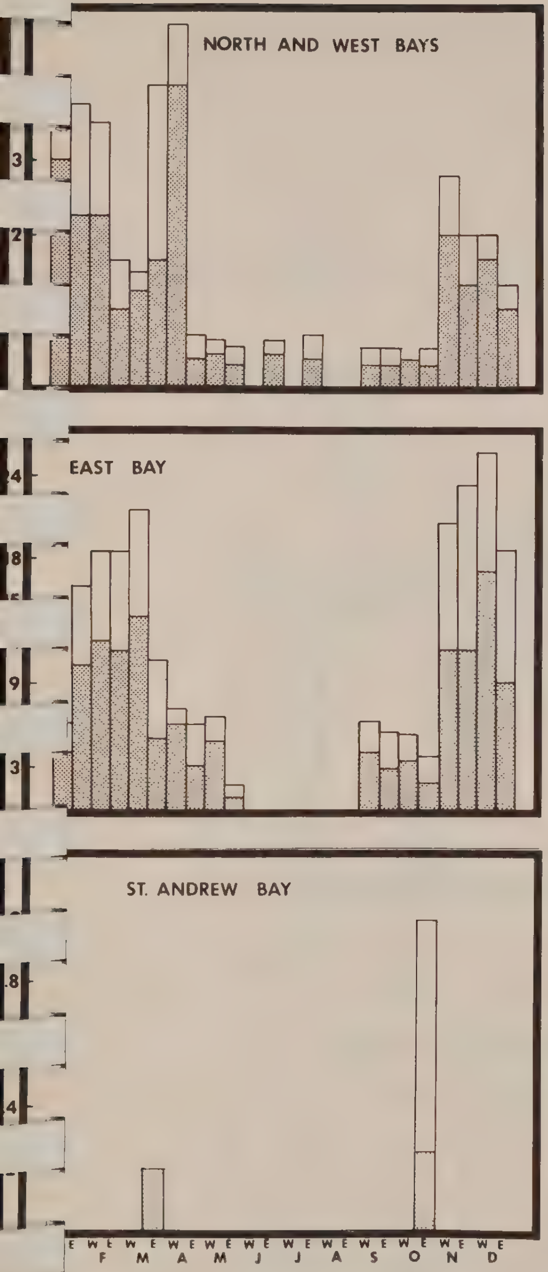
The estimated numbers of commercial crabbers crab boats are shown in Figure 31 for areas, weekday and weekend-days each month in 1973. No tran boats were observed.

All observed crab fishing was by baited lift traps th were set and hauled from small boats. Large quantities crabs are harvested by shrimpers, however, incid their shrimp catches.

DISCUSSION

The need for reasonably accurate statistics o and economic value of recreational fishing and relate activities in marine-estuarine waters is well recognize by resource managers, environmentalists, scienti others. While commercial, industrial, municipal, residential uses of these waters and resources are genera ly accepted by the public as being in the public i to optimize their social, economic, and bi benefits the recreational user necessarily has to be considered.

The waters of the coastal zone offer a great va recreational opportunities. Fishing, boating, and ming are examples. A complete and reliable survey of a recreational activities in St. Andrew Bay and adjacen coastal waters would involve such enormous eff



ıre 25.—Estimated average daily instantaneous numbers of l oyster fishermen (light) and boats (dark) by areas, (W), and weekend-days (E) each month in 1973. None observed in coastal waters.

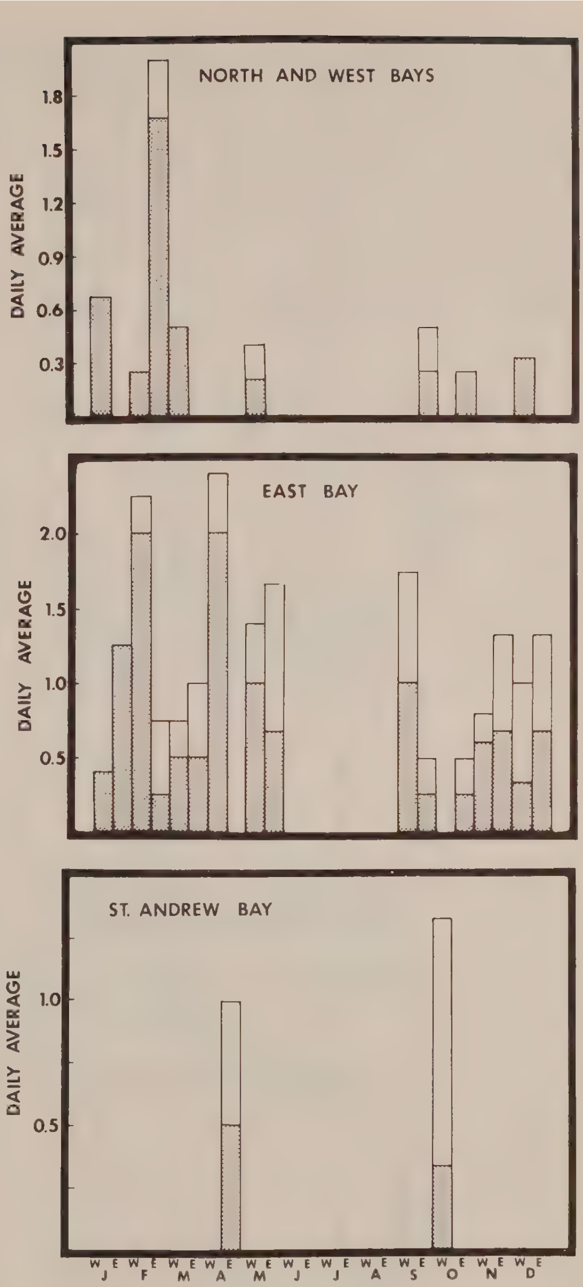


Figure 26.—Estimated average daily instantaneous numbers of transit commercial oyster fishing boats (dark) and occupants (light) by areas, weekdays (W), and weekend-days (E) each month in 1973. None was observed in coastal waters.

to preclude such an undertaking. For the ns no attempt was made to obtain an estimate e total participation in a single activity. Still, the by management for statistical data on public of the area's living resources and space The fishery biologist often has to conduct ively inexpensive surveys for short-term solutions to nt problems. The results are not always his survey might best be regarded as exploratory in that the results are resonably accurate, although not totally comprehensive, and were not overly expensive to obtain.

In this survey, estimates of the number of recreational and commercial fishermen and boaters were obtained by methods that permit direct comparison of expended effort for each fishery resource and boating activity in each of the major areas on weekdays, weekend-days, and months in 1973. The estimates were also made by type of fishing platform and method of fishing. From these estimates the resource manager can appraise the competitive effort between recreational and commercial fishermen for the same resource, the time when the greater or lesser competition occurs, and where and how it occurs. The estimates also provide the manager with possible solutions to competitive problems by manipulating the time, place, and method of harvest.

Estimates of the economic benefits of daytime recreational angling were computed for two primary reasons: one, for the public awareness of the oni spent by anglers for their recreation; and two, f managerial consideration in matters relating equitable allocation of the natural resources amo groups.

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I thank F. W. Bell and C. R. Futch for reviewing thi manuscript, and the following laboratory staff membe

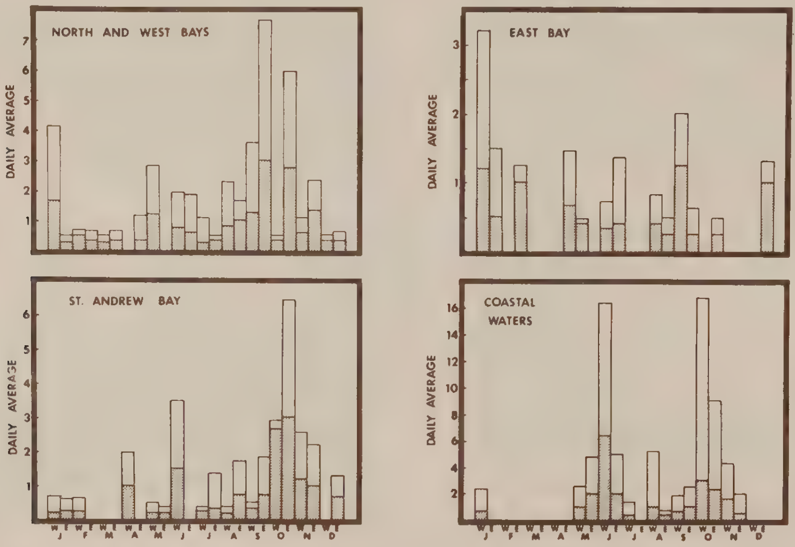

Figure 27.—Estimated average daily instantaneous numbers of commercial finfish fishermen (light) and boats (dark) by areas, weekday (W), and weekend-days (E) each month in 1973.

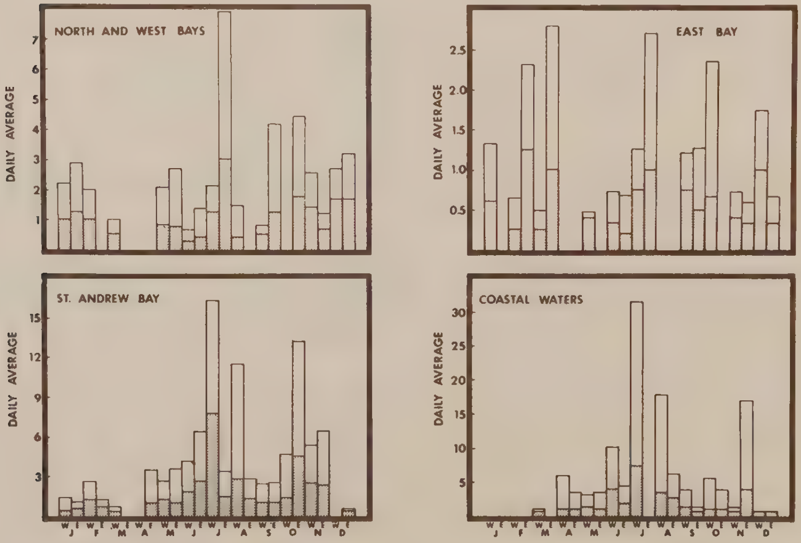

Figure 28.—Estimated average daily instantaneous numbers of commercial finfish fishing boats (dark) and occupants (light) by areas, weekdays (W), and weekend-days (E) each month in 1973.

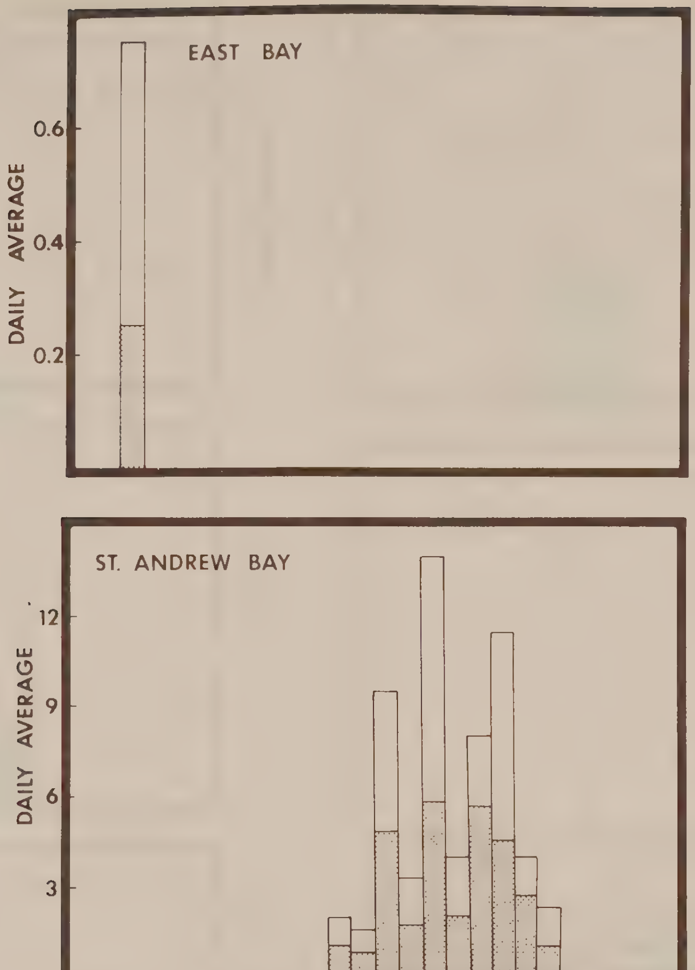

Figure 29.—Estimated average daily instantaneous numbers of transit commercial scallop fishermen (light) and boats (dark) by areas, weekdays (W), and weekend days (E) each month in 1973. None was observed in North and West Bays.

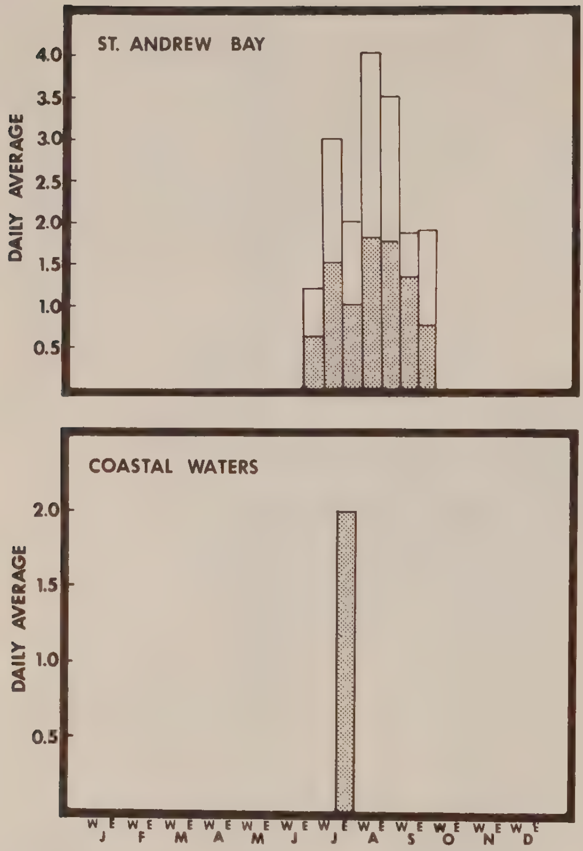

Figure 30.—Estimated average daily instantaneous numbers of transit commercial scallop fishing boats (dark) and occupants (light) by areas, weekdays (W), and weekend-days (E) each month in 1973. None was observed in North, West, and East Bays.

who helped conduct the survey: Dennis F. Anderson, Harold A. Brusher, Nelson L. May, David C. Muenzel, Leslie W. Touart, and W. Lee Trent.

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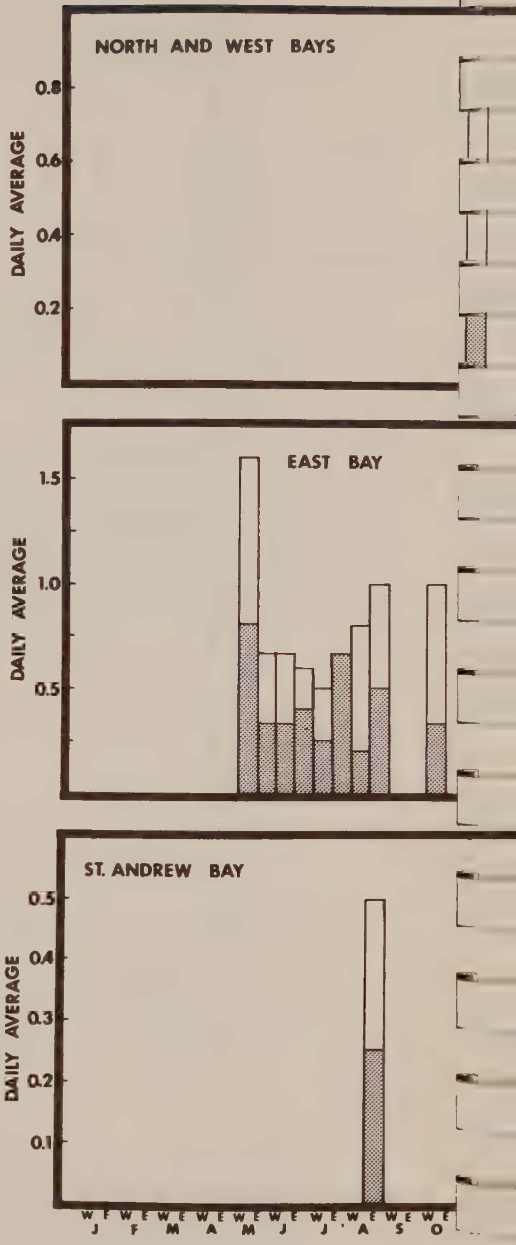

Figure 31.—Estimated average daily instantaneous numbe commercial crab fishermen (light) and boats (dar weekdays (W), and weekend-days (E) each month i was observed in coastal waters.

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Seasonal Bottom-Water Temperature Trends in the Gulf of Maine and on Georges Bank, 1963-75

Clarence W. Davis

May 1978

U.S. DEPARTMENT OF COMMERCE
Juanita M. Kreps, Secretary
National Oceanic and Atmospheric Administration
Richard A. Frank, Administrator
National Marine Fisheries Service

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Seasonal Bottom-Water Temperature Trends in the Gulf of Maine and on Georges Bank, 1963-75

CLARENCE W. DAVIS[1]

ABSTRACT

Spring (1968-75) and autumn (1963-75) bottom-water temperatures in the Gulf of Maine and on Georges Bank were analyzed to investigate a suspected warming trend in the region. During the spring the mean temperature in the Gulf of Maine increased rather steadily from a low of 5.4°C in 1968 to a high of 6.4°C in 1974. Various subareas of the Gulf had more frequent and greater oscillations but exhibited the same overall warming trend. Mean spring temperatures on Georges Bank fluctuated from 3.8°C in 1968 to 6.3°C in 1974 and declined by nearly 2°C in 1975 with similar characteristics in eastern, central, and western subareas of the Bank.

During the autumn in the Gulf, bottom-water temperatures reached a minimum of 5.4°C in 1966, increased to a maximum of 8.4°C in 1973 and 1974, but declined to 8.0°C in 1975. Subareas of the Gulf generally showed the same temperature trends from 1963 to 1968; especially notable are the cooling trend west of long. 69°W which commenced in 1971, and a decrease in all five subareas in 1975. Georges Bank temperatures in autumn declined from a maximum of 13.1°C in 1965 to a minimum of 10.4°C in 1969, reached another peak of 12.6°C in both 1973 and 1974, but declined to 11.6°C in 1975. Subareas of Georges Bank generally followed the same pattern with the eastern third of the Bank usually 2°C or colder than either of the other subareas in the autumn.

The average bottom-water temperatures during spring were 5.0°C on Georges Bank and 6.1°C in the Gulf of Maine; temperatures in the autumn were 11.7°C and 7.2°C, respectively, for these areas.

INTRODUCTION

s study summarizes variations in bottom-water ratures observed during spring (1968-75) and autumn (1963-75) groundfish surveys conducted by the Gulf of Maine-Georges Bank area by the National e Fisheries Service, Woods Hole, Mass. Relatively high temperatures were observed during 1973 and 1974 and raised the question of whether there had been a sig-nifi nt upward trend in average temperatures or simply le of anomalous years since the surveys began in 1963.

Recent papers by Colton and Stoddard (1973), Colton), and Schopf (1967) have summarized the dis- on of bottom-water temperatures from 1940 to 1967 in the Gulf of Maine and contiguous waters. A contemporary paper by Karaulovsky and Sigaev[2] sum- s similar data for 1962-72 and provides an inter- te comparison between the earlier papers and this present study. These previous studies are not strictly comparable with the present study because of the ility of the data bases and different analytical methods; nevertheless, comparisons are useful for the identification of long-term trends, and the analyses are considered adequate for approximating annual changes ng and autumn bottom temperatures in the Gulf of Maine and on Georges Bank.

Numerous authors, including Dow (1966, 1969) and Sutcliffe et al. (1977) for Gulf of Maine waters, have used surface-water temperatures to correlate fish catch with environmental factors. Flowers and Saila (1972) used both surface and bottom temperatures to estimate yield of American lobsters, *Homarus americanus*, and found the latter parameter considerably more accurate.

Although a study of bottom-water temperatures alone represents only a partial analysis of the temperature structure of the region, they are sufficient to reveal major changes in the thermal environment and are particularly relevant to the distribution of benthic organisms. The remainder of the temperature profile, from surface to near bottom, is not included in this study. Salinity profiles are also excluded since only surface and bottom data were routinely obtained until the most recent years. For these reasons, specific identification of subsurface water masses is speculative. It is known, however, that the major source of subsurface water in the Gulf of Maine is the inflow of relatively warm slope water through the Northeast Channel (Bigelow 1927; Colton 1968b). Therefore, major changes in the average bottom-water temperatures in much of the Gulf may be closely related to changes in the volume and extent of this inflow.

Georges Bank water is derived largely from the Gulf of Maine, but it is also sporadically influenced by intrusions of slope water along its southern boundary (Bumpus[3]). In the spring a counterclockwise (cyclonic) eddy is

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east Fisheries Center, National Marine Fisheries Service, Woods Hole, MA 02543.

[2] Karaulovsky, V. P., and I. K. Sigaev. 1976. Long-term variations n heat content of the waters on the Northwest Atlantic Shelf. Int. Northwest Atl. Fish. Res. Doc. 76/2, 9 p.

[3] Bumpus, D. F. 1975. Review of the physical oceanography of Georges Bank. Int. Comm. Northwest Atl. Fish. Res. Doc. 75/107, 32 p.

present in the Gulf of Maine and may either divert into Cape Cod Bay or turn eastward along the northern edge of Georges Bank. Similarly a clockwise (anticyclonic) eddy over Georges Bank causes a persistent westerly drift along the southern edge of the Bank which continues across Great South Channel. During autumn the southern portion of the Gulf eddy breaks down into a drift across the Bank, thus affecting temperatures there (Bumpus and Lauzier 1965). Since the Bank is well mixed vertically by tidal and wind forces throughout most of the year, subsurface temperatures there are influenced largely by air-sea interactions and by advection of deeper waters.

The identification of temperature anomalies on an areal and seasonal basis, along with other supportive data, is useful for interpreting changes in biological phenomena observed during these years. Examples of such changes are discussed in this paper.

METHODS

Bottom temperature data are based on mechanical or expendable bathythermograph observations obtained randomly during spring and autumn groundfish surveys (Grosslein[4]). During each cruise approximately 75-100 observations were made in the Gulf of Maine, mostly in water depths of 100-275 m, and 50-60 observations on Georges Bank (Fig. 1). Only those waters shallower than 100 m on Georges Bank are considered in this re because of high temperature variability of greater de caused by sporadic excursions of warm slope water a g the Bank's southern edge. Raw temperature observations are assumed to be actual bottom temperat because only a few stations in the inner Gulf of Main ceeded the maximum depth capability of 275 m of mechanical bathythermographs. Since temperatures below 250 m in most of the Gulf are generally isother with depth, 275-m temperatures are representativ bottom temperatures. Expendable bathythermographs, capable of reaching the greatest depths encountered, were used after 1969.

Both the Gulf of Maine and Georges Bank were ana ed in their entirety and by subareas which are bands of one degree of longitude in width (Fig. 1). Subareas in the Gulf are identified by Roman numerals I-V and Geo Bank subareas are termed Western, Central, a Eastern Georges Bank. Analysis by one-degree segments of longitude was chosen as they define rather dist physiographic regions of the Gulf and Bank (Tabl and also this was a convenient arbitrary method of establishing segment boundaries to show suspected temperature differences and trends in varous parts of the s area. Analysis of temperatures by latitude was no tempted, but latitudinal variability has been documented for both the shoal and deep waters of the Gulf of Maine (Bigelow 1927) and Georges Bank (Sigaev[5]).

Contoured isotherms at 1°C intervals were overlai 5-min grid charts and the number of units counted to determine the percentage area represented by each 2°C temperature class interval (TCI) (Figs. 2, 3). An inde the mean seasonal bottom temperature was then culated by multiplying the midpoint temperature of each

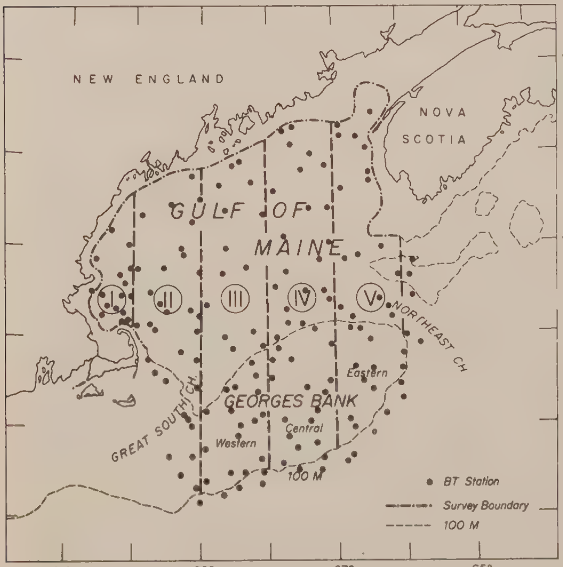

Figure 1.—Gulf of Maine-Georges Bank and subarea boundaries used in analysis of bottom-water temperature data. (Dots represent typical distribution of BT stations).

Table 1.—Gulf of Maine and Georges Bank subarea characteristics.

Area	Subarea	Characteristics
Gulf of Maine:	I	Coastal, < 200 m, Jeffreys Ledge and Stellwagen Bank
	II	Western Basin, some banks and ledges
	III	Intermediate between II & IV
	IV	Eastern Basin, mostly>200 m
	V	Coastal western Nova Scotia, entrance N west Channel
Georges Bank:	Western	Cultivator Shoal, adjacent Great South Channel
	Central	Georges Shoal, no adjacent channels
	Eastern	Mostly>60 m, adjacent Northeast Chan

Figure 2.—Distribution of spring bottom-water temperatu 75. (Dotted areas represent Georges Bank temperatures 4°C; gridded areas represent Gulf of Maine temperatures gre than 8°C.)

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[4] Grosslein, M. D. 1974. Bottom trawl survey methods of the Northeast Fisheries Center, Woods Hole, Massachusetts, USA. Int. Comm. Northwest Atl. Fish. Res. Doc. 74/96, 27 p.

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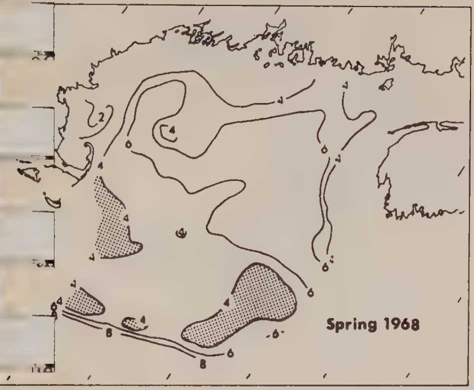
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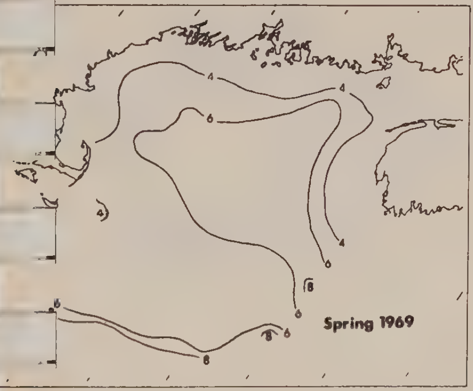
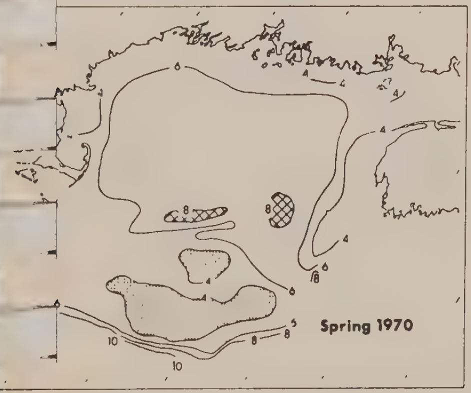
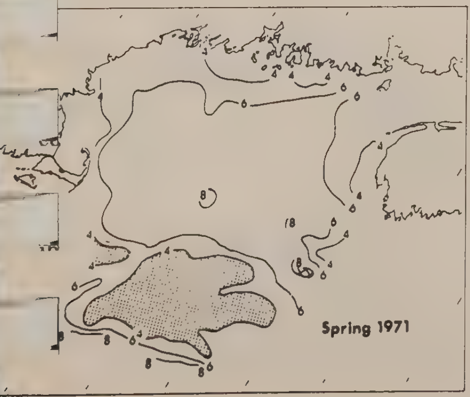

Spring 1969


Spring 1970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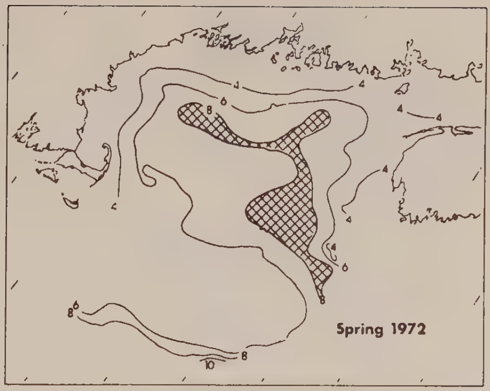
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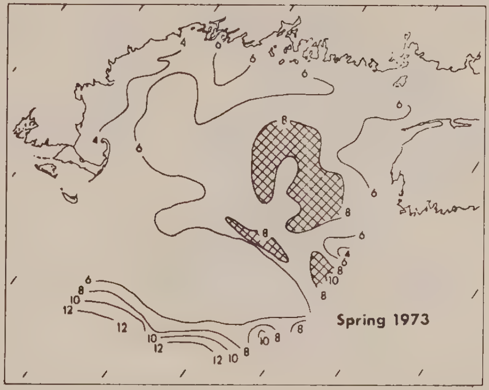
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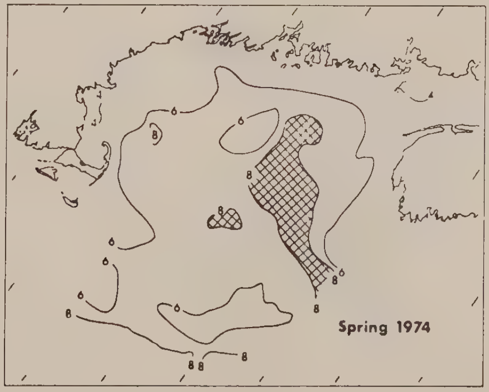
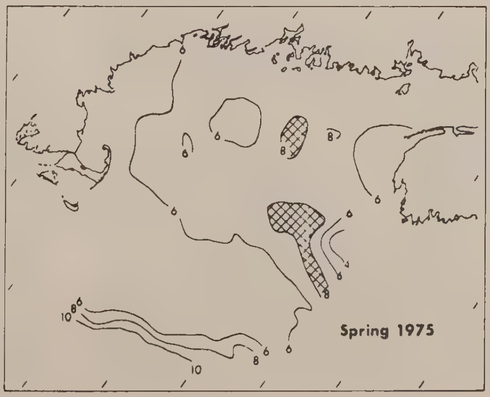

Spring 1974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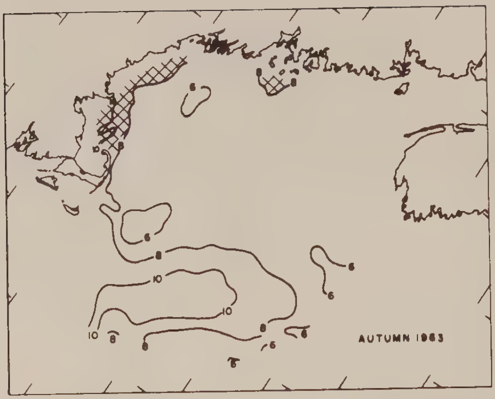
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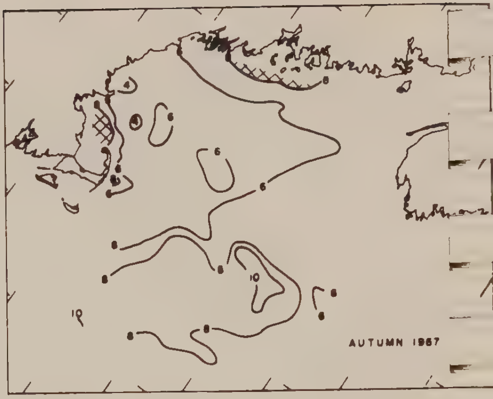
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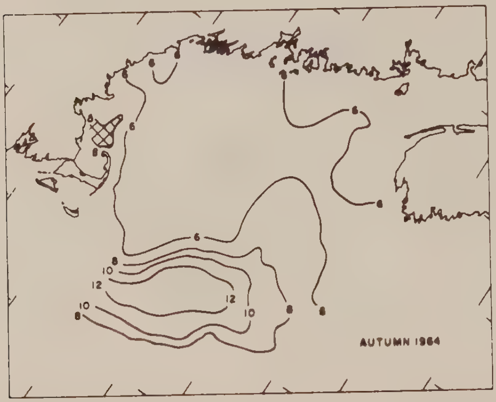
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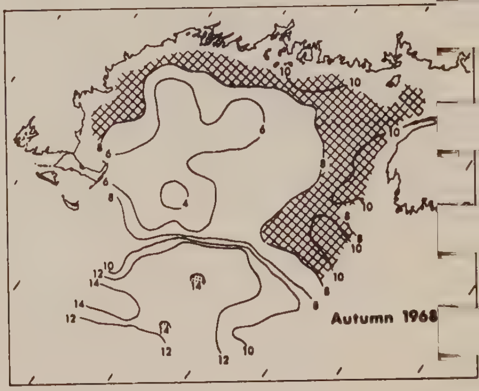
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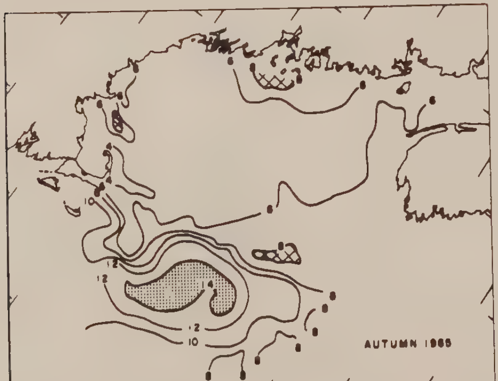
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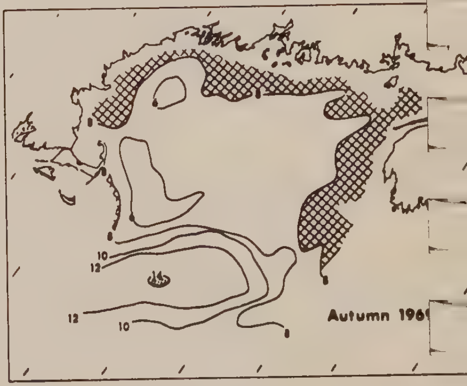
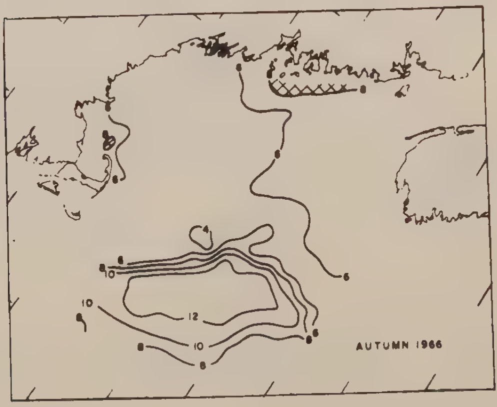

Autumn 196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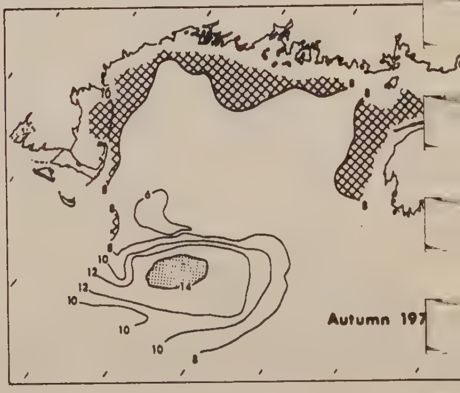
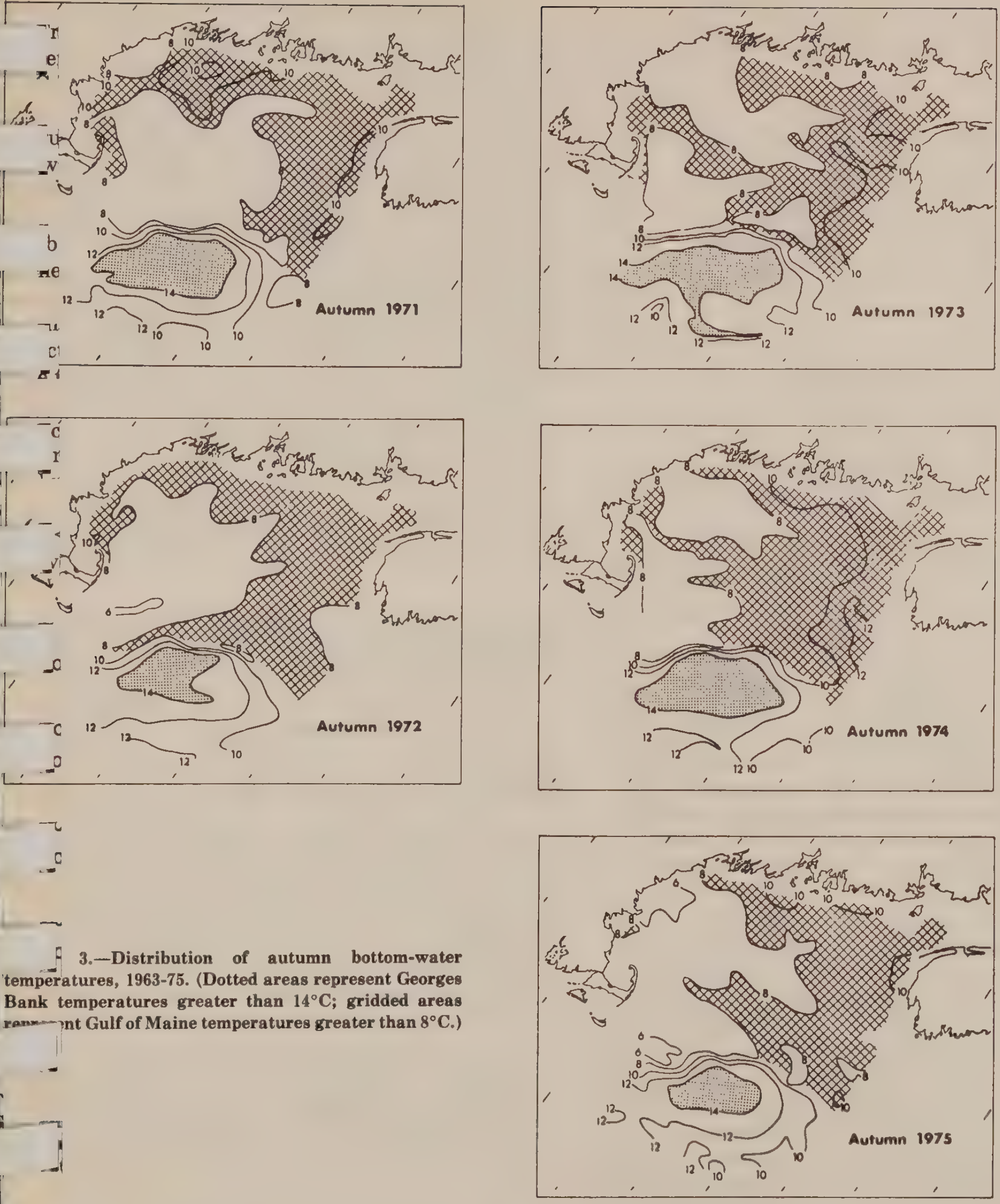

Autumn 197



3.—Distribution of autumn bottom-water temperatures, 1963-75. (Dotted areas represent Georges Bank temperatures greater than 14°C; gridded areas represent Gulf of Maine temperatures greater than 8°C.)

y the percentage area within that interval and ividing the total by 100. This method was chosen as it was ot possible to make direct year-to-year comparif station data because randomly located stations ere sampled during each cruise. The stratified random ampling scheme did, however, result in representative ing by depth and geographic subareas. This d also eliminates bias associated with depth variability as the indices derived are based solely on an areal basis and the same geographic areas are used to re relative annual differences in bottom-water atures. Since no attempt is made to determine bsolute temperature indices, the method chosen for data analysis seems justified. For illustrative purposes, portions of the histograms of TCI distributions have been shaded to emphasize temperature extremes. For Georges Bank TCI's < 4° and > 8°C in spring (Figs. 7, 9) and < 6° and > 10°C in autumn (Figs. 15, 17) are shaded. For the Gulf of Maine TCI's < 4° and > 6°C in spring (Figs. 11, 13) and < 8° and > 14°C in autumn (Figs. 19, 21) are shaded. The shaded portions of the histograms generally lie outside expected mean bottom temperature conditions.

Dates for the collection of temperature data are shown in Figure 4. The effects of irregular seasonal sampling are difficult to interpret, especially for shoal areas like Georges Bank where seasonal cycles of bottom-water

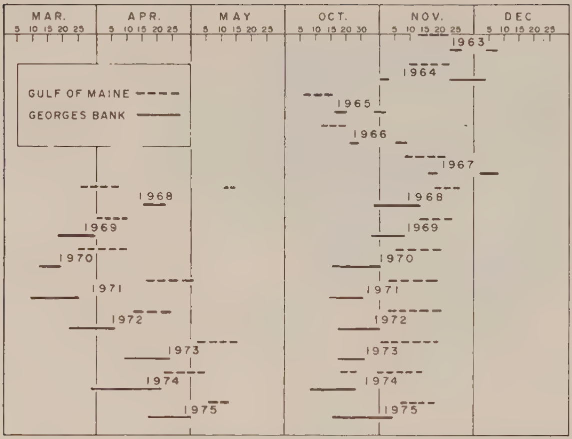


Figure 4.—Dates of spring and autumn cruises in the Gulf of Maine and Georges Bank, 1963-75.

temperatures are largely influenced by highly variable surface conditions. The dates of cruises on Georges Bank were fairly consistent in autumn, but spring cruises had two rather distinct groupings—March dates for 1969-72 and April dates for the remaining 4 yr. In the Gulf autumn cruise dates nearly all overlapped temporally and spring cruises occurred mostly when the bottom-water temperatures remain virtually stable and isolated from surface effects (Bigelow 1927; Colton and Stoddard 1973). It was assumed in an earlier report (Davis[6]) that timing of the cruises was not critical to the estimation of major temperature trends because most of the data were collected during or close to the seasonal maxima or minima in temperatures (Colton and Stoddard 1972). In this report, however, the cruises have been adjusted to common reference dates (April 20 and November 9 for the Gulf; April 4 and November 7 for the Bank). Average bottom temperatures by 10-day intervals at Portland and Nantucket Lightships (Fig. 5) were used to calculate adjusted values for the Gulf of Maine and Georges Bank, respectively. The mean temperatures observed on each cruise for the whole area and its subareas were adjusted by adding or subtracting the differences in the mean temperatures at the appropriate lightship on the reference dates and on the middates of the cruise and subarea samplings. Magnitude of the adjustments was mostly less than 0.4°C in the Gulf of Maine, but was 1°C or more on Georges Bank, especially in the autumn (Figs. 6, 10, 14, 18; Tables 2-5). Finally an annual index for both the Gulf of Maine and Georges Bank was obtained by averaging the spring and autumn indices (Fig. 22).

The reader is alerted to keep in mind which index—observed or adjusted—is used in the text. Adjusted values are intended primarily for examining trends and observed values for comparing habitat conditions, i.e., TCI distributions.

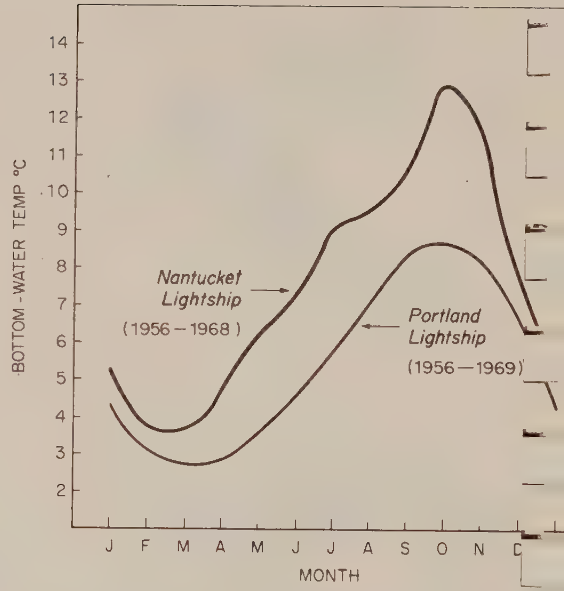


Figure 5.—Mean annual cycles of bottom-water temperat Nantucket (1956-68) and Portland (1956-69) Lightships (data Chase, Woods Hole Oceanographic Institution).

RESULTS

Spring Temperatures, 1968-75

Gulf of Maine—Spring.—Adjusted mean bo water temperatures for the Gulf of Maine sho warming trend after the coldest year, 1968, with pea temperatures of 6.5°C in 1970 and 6.4°C in 1974 (Fig 6) Annual decreases of 0.3°C were observed in 197 1975, while the largest annual increase of 0.8°C occ in 1970 and accounted for over 70% of the total 8-yr rang of 1.1°C (5.4-6.5°C). The 1968-75 mean index of 6.1°C was about 1°C colder than in 1955 and 1956, bu warmer than in 1965 and 1966 as reported by S (1967), and also 1°C warmer than the 1962-72 long-tern

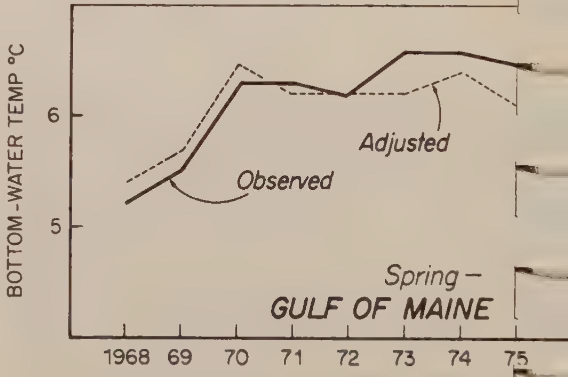


Figure 6.—Observed and adjusted mean bottom-water temp in the Gulf of Maine during the spring, 1968-75.

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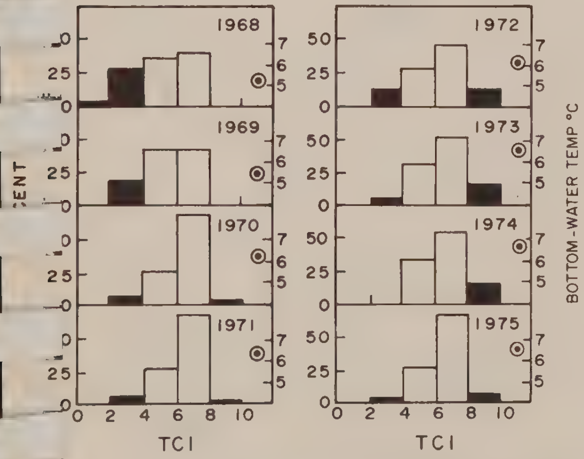
[6] Davis, D. W. 1976. Spring and autumn bottom-water temperatures in the Gulf of Maine and Georges Bank, 1968-1975. Int. Comm. Northwest Atl. Fish. Res. Doc. 76/85, 14 p.

mean reported by Karaulovsky and Sigaev (see footnote rom these earlier reports, it appears that the erature peaked at 7°C in 1955, declined to a low of 4.3°C in 1966, and has fluctuated between 6.1° and 6.5°C since 1970.

ure 7 illustrates the changes in proportions of bot- vater covered by various TCI's for the entire Gulf. Although some years had the same or nearly the same mean observed temperature, the TCI's were often quite ble. For example, during the spring cruises of 1970- e observed means varied by only 0.1°C, but the percentage of water in the coldest and warmest TCI's (solid in histogram) varied by factors of about 2 and 13, ctively). The 6°-8°C TCI dominated in all years while the 4°-6°C TCI remained the most consistent during the study period. The general warming trend is cterized by a rather progressive decrease of water near shore with a corresponding increase of water >8°C mostly in the eastern basin of the Gulf (Fig. 2). No water <4°C was evident in 1974, while a small amount of <2°C contributed to the coldest index which was ved in 1968.



igure 7.—Percentages of temperature-class intervals (TCI's) in the ulf Maine during the spring, 1968-75. (Dotted circles represent rved mean bottom-water temperatures; solid bars emphasize ture extremes.)

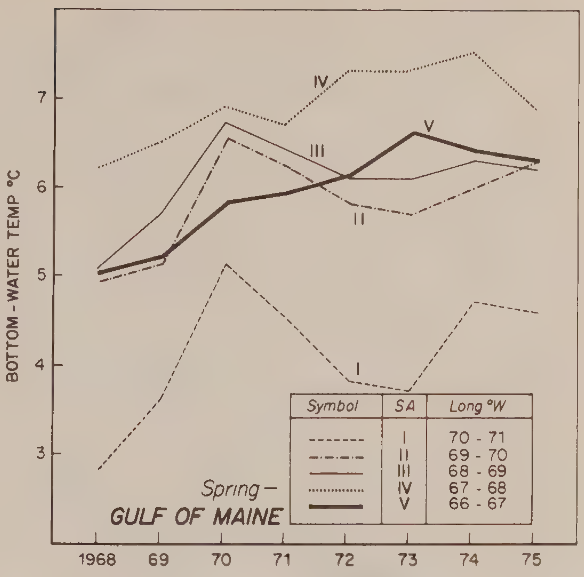


Figure 8.—Adjusted mean bottom-water temperatures in the Gulf of Maine in subareas I-V during the spring, 1968-75.

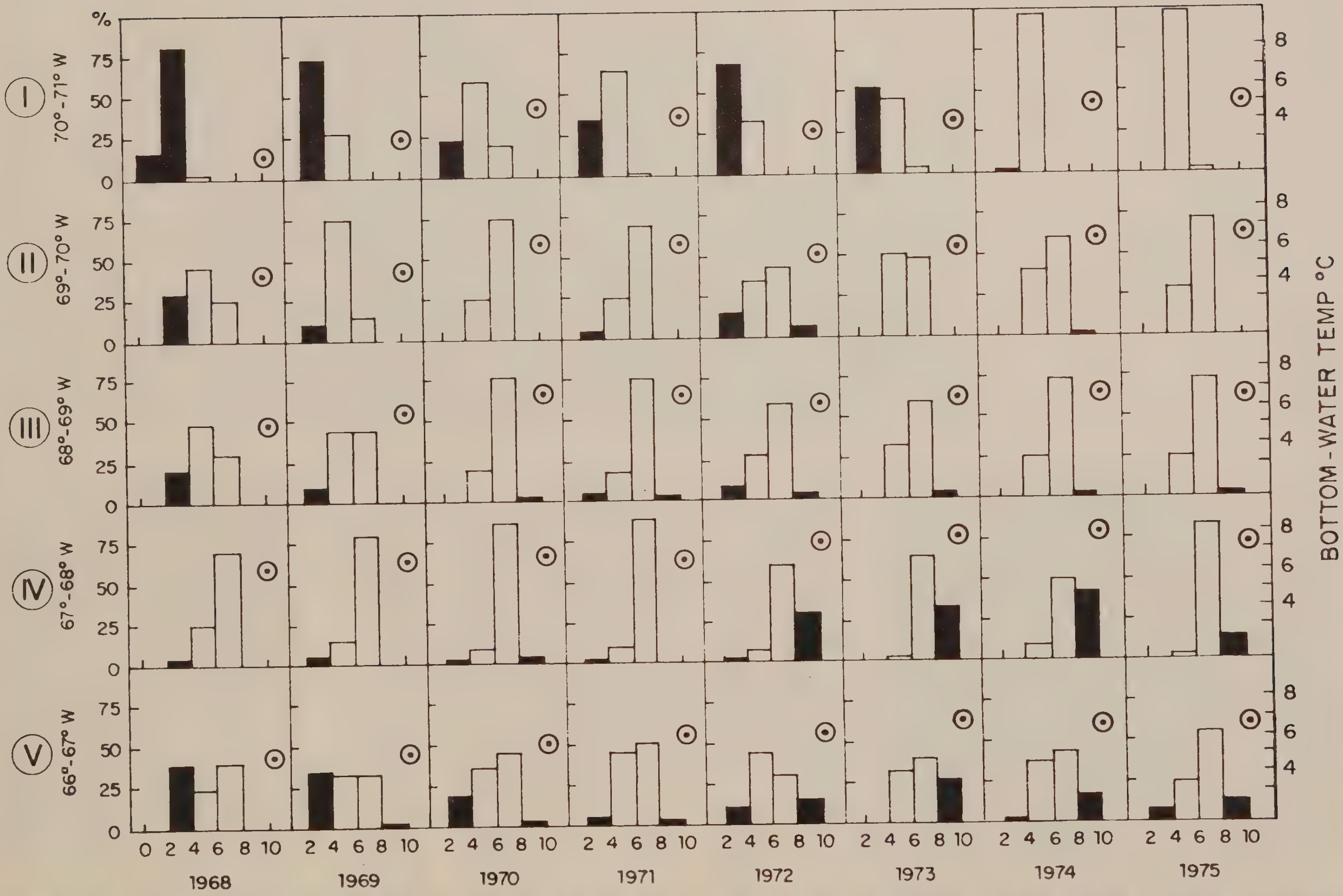
areas of the Gulf of Maine—Spring.—Adjusted of the annual mean bottom-water temperature or the Gulf by subareas of one-degree longitude are summarized in Figure 8. Analysis by subareas reveals an in- in the frequency and magnitude of oscillations n years with an overall warming trend indicated or each subarea. Subareas I and IV had the lowest and bottom temperatures, respectively, during all This is associated with differences in bathymetry s Subarea I has the most shoal water and nearly all of ubarea IV is greater than 200 m deep. The relative ss of Subarea I is also reflected in the large tem- e variability between years, especially the in- reases between 1969 and 1970 (+1.5°C), and between 1973 and 1974 (+1.0°C), and the decreases between 1970 and 1971 (−0.6°C) and between 1971 and 1972 (−0.7°C). A temperature increase was noted in all subareas in 1968-70 with the sharpest rise between 1969 and 1970. In no year was a decrease observed for all five subareas.

The 8-yr means and annual anomalies are summarized in Table 2 and show that all subareas had negative values in 1968 and 1969 and positive values in 1974 and 1975, but a mixture of values in the intervening years.

Comparison of the Gulf by subarea again shows how years of similar mean temperatures can have vastly different TCI's (Fig. 9). In Subarea I the observed means were all 5°C in 1970, 1974, and 1975, but the TCI's in 1970 were about 20% each for the 2°-4°C and 6°-8°C intervals, and 60% for the 4°-6°C interval, while 1974 and 1975 were both nearly 100% for the 4°-6°C interval. Conversely, a deep stable subarea like IV had very similar TCI percentages when the spring means were similar and clearly shows the decrease in coldest and increase in warmest TCI's as the warming trend progressed.

Table 2.—Mean bottom-water temperatures and anomalies for Gulf of Maine, spring 1968-75. Adjusted values are shown in parentheses.

Subarea	Mean	1968	1969	1970	1971	1972	1973	1974	1975
I.	4.2 (4.1)	-1.5 (-1.3)	- .7 (- .5)	+ .8 (1.0)	+ .2 (+ .5)	- .5 (- .3)	- .2 (- .4)	+ .8 (+ .6)	+ .8 (+ .5)
II	5.9 (5.8)	-1.0 (- .9)	- .8 (- .7)	+ .6 (+ .7)	+ .3 (+ .4)	- .1 (0)	+ .1 (- .1)	+ .3 (+ .2)	+ .4 (+ .5)
III	6.2 (6.1)	-1.1 (-1.0)	- .5 (- .4)	+ .5 (+ .6)	+ .3 (+ .3)	- .1 (0)	+ .2 (0)	+ .3 (+ .2)	+ .3 (+ .1)
IV	7.0 (6.9)	- .7 (- .7)	- .5 (- .4)	- .1 (0)	- .2 (- .2)	+ .4 (+ .4)	+ .6 (+ .4)	+ .7 (+ .6)	+ .2 (0)
V	6.0 (5.9)	-1.0 (- .9)	-1.0 (- .7)	- .3 (- .1)	0 (0)	0 (+ .2)	+ .8 (+ .7)	+ .5 (+ .5)	+ .5 (+ .4)
Entire Gulf	6.1 (6.1)	- .9 (- .7)	- .6 (- .4)	+ .2 (+ .4)	+ .2 (+ .1)	+ .1 (+ .1)	+ .5 (+ .1)	+ .5 (+ .3)	+ .4 (0)


I 70°-71° W
II 69°-70° W
III 68°-69° W
IV 67°-68° W
V 66°-67° W
%
0
25
50
75
BOTTOM-WATER TEMP °C
4
6
8
0 2 4 6 8 10
2 4 6 8 10
1968
1969
1970
1971
1972
1973
1974
1975

orges Bank—Spring.—Adjusted spring bottom- temperatures on Georges Bank (Fig. 10) are characterized by a low in 1971 of 3.8°C, followed by rather large annual increases to a peak of 6.3°C in 1974, then a sharp decline of 1.9°C in 1975. The 8-yr of 5.0°C is 1°C lower than that reported by Karaulovsky and Sigaev (see footnote 2) for 1962-72, but their coverage included waters deeper than 100 m which ably accounts for much of the difference. Data from pf (1967) indicate a mean Georges Bank bottom-water temperature in the spring of approximately 6°C in 1955, 4.5°C in 1956, 3°C in 1965, and 3.5°C in 1966.

orges Bank is usually dominated by the 4°-6°C TCI in the spring which in 1969 accounted for 90% of the area within the 100-m isobath (Fig. 11). The minimum (1971) maximum (1974) observed means were influenced by lacement of the 4°-6°C TCI with 2°-4°C and 6°-8°C water, respectively. Since the Bank waters are well mixed vertically in the spring, these changes in TCI percentages in 1971 and 1974 reflect broad-scale differences from average habitat conditions.

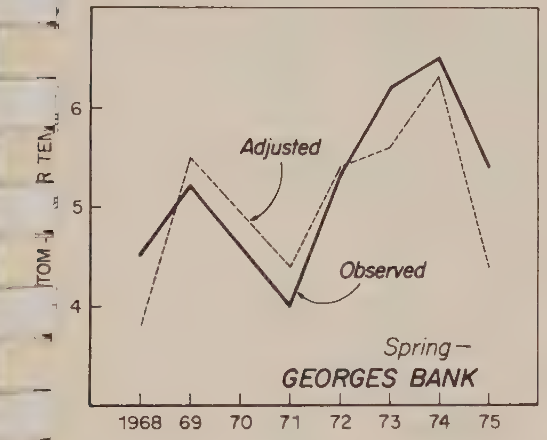
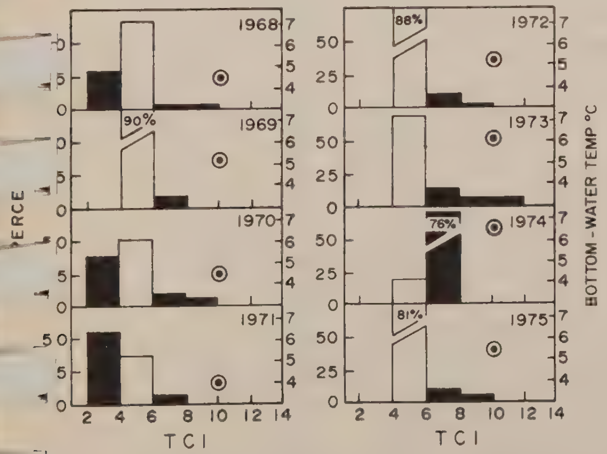


Figure 10.—Observed and adjusted mean bottom-water temperatures on Georges Bank during the spring, 1968-75.



e 11.—Percentages of temperature-class intervals (TCI's) on Georges Bank during the spring, 1968-75. (Dotted circles represent the observed mean bottom-water temperatures.)

Subareas of Georges Bank—Spring.—Unlike the Gulf of Maine, year-to-year changes in spring temperatures were similar in all the subareas of Georges Bank, which emphasizes the homogeneity of these shoal waters (Fig. 12). Central Georges Bank, which has the highest proportion of shoal water, was usually the coldest of the three subareas and reached a minimum of 4.0°C in 1971. Western and Eastern Georges Bank had very similar mean temperatures except in 1968 when Eastern Georges Bank reached the time-series minimum of 3.6°C for all subareas and had an anomaly of −1.7°C (Table 3).

Subarea TCI's for spring are shown in Figure 13. It is interesting to note that the warm years of 1973 and 1975 (observed means) were substantially influenced by water >8°C in all three subareas, but that the warmest year, 1974, had none of this water. The rather low observed mean for the entire Bank in 1968 was mainly the result of a 2°-4°C TCI covering 75% of the eastern subarea; water

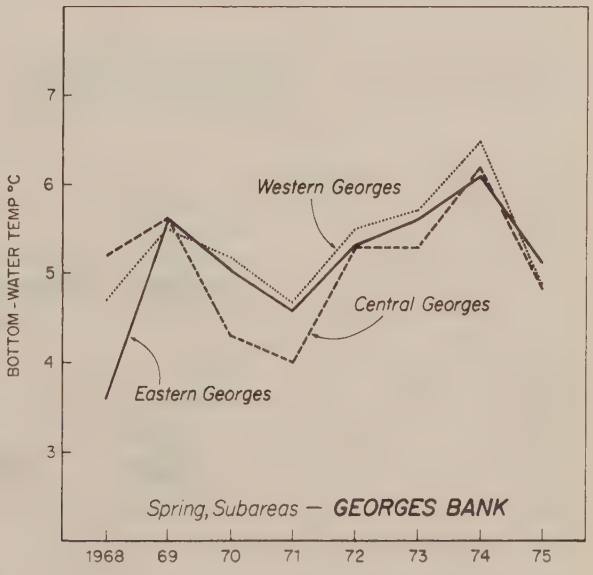


Figure 12.—Adjusted mean bottom-water temperatures on Georges Bank by subareas during the spring, 1968-75.

Table 3.—Mean bottom-water temperatures and anomalies for Georges Bank, spring 1968-75. Adjusted values are shown in parentheses.

Subarea	Mean	1968	1969	1970	1971	1972	1973	1974	1975
Western	5.3 (5.3)	- .7 (-1.6)	- .1 (+ .2)	- .3 (- .1)	-1.1 (- .6)	0 (- .3)	+ .9 (+ .5)	+1.4 (+1.3)	+ .2 (- .4)
Central	5.1 (5.1)	0 (+ .1)	+ .1 (+ .5)	-1.0 (- .8)	-1.5 (-1.1)	+ .1 (+ .2)	+ .7 (+ .2)	+1.4 (+1.1)	+ .4 (- .3)
Eastern	5.2 (5.1)	-1.7 (-1.5)	.0 (+ .5)	- .4 (- .1)	-1.0 (- .5)	0 (+ .2)	+1.0 (+ .5)	+1.2 (+1.0)	+ .6 (0)
Entire Bank	5.2 (5.0)	- .7 (-1.2)	0 (+ .5)	- .6 (0)	-1.2 (- .6)	+ .1) (+ .4)	+1.0 (+ .6)	+1.3 (+1.3)	+ .2 (- .6)

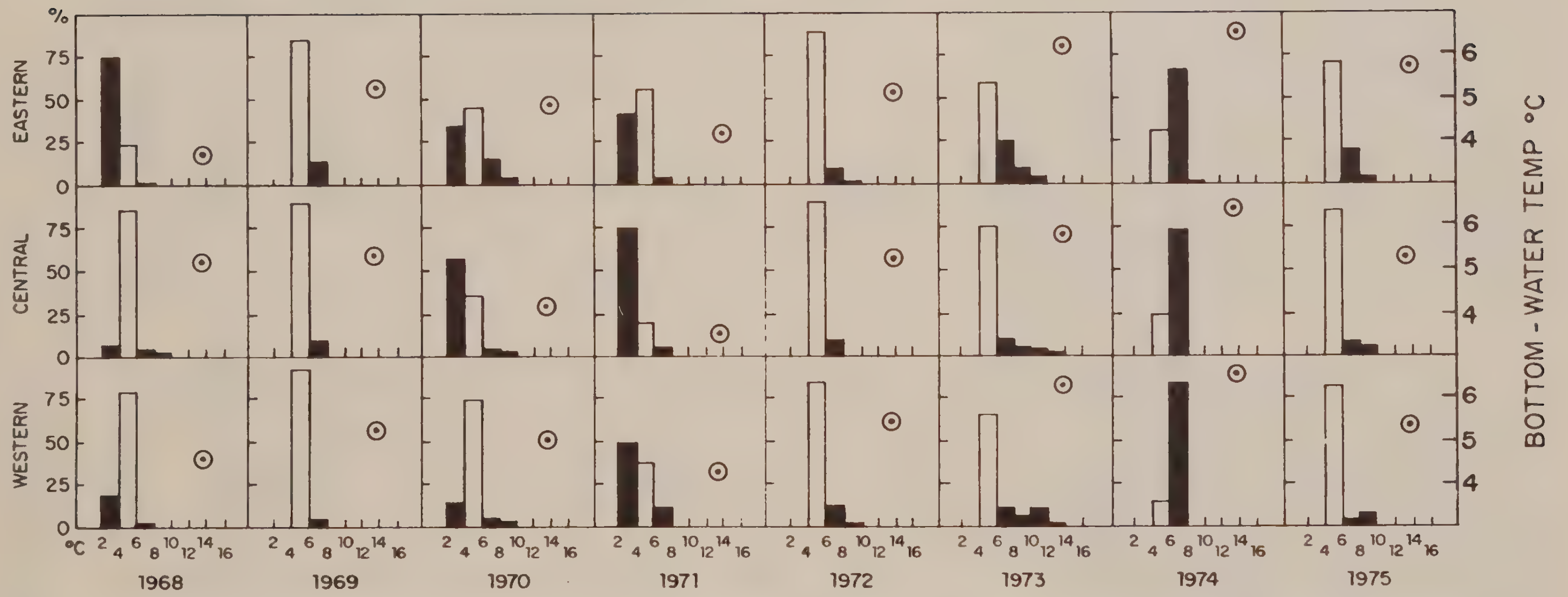


Figure 13.—Percentages of temperature-class intervals (TCI's) on Georges Bank by subareas during the spring, 1968-75. (Dotted circles represent the observed mean bottom-water temperatures.)

this cold occurred there in only two other years, 1970 and

Autumn Temperatures, 1963-75

lf of Maine—Autumn.—Adjusted bottom-water temperatures during autumn in the Gulf of Maine decreased from a mean of 7.2°C in 1963 to a time-series hum of 5.4°C in 1966, and then increased to a max- of 8.4°C in 1973 and 1974 (Fig. 14). The greatest changes were the 1.5°C decrease between 1963 and 1964 and the 1.5°C increase between 1967 and 1968. Every after 1967 exceeded the 13-yr mean of 7.2°C, while ior years had negative anomalies (Table 4). The 1963-75 mean was only 0.2°C warmer than that observed by Karaulovsky and Sigaev (see footnote 2) for 72 and about 1°-1.5°C warmer than in 1964 and 196 and the same as in 1955 as observed by Schopf (1967).

nperature class intervals in the Gulf varied an- y even though the observed mean temperatures varied only slightly between years (Fig. 15). Generally, water<6°C in the coldest years was partially "replaced" ter >10°C and dominance of the 6°-8°C TCI shifted 8°-10°C TCI to account for the changes in the warmest years. The observed decline in 1975 was a result of an increase in 4°-6°C water with a corresponding ase of water >10°C.

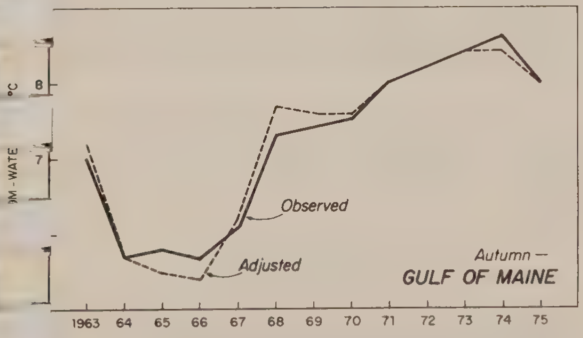


Figure 14.—Observed and adjusted mean bottom-water temperatures in the Gulf of Maine during the autumn, 1963-75.

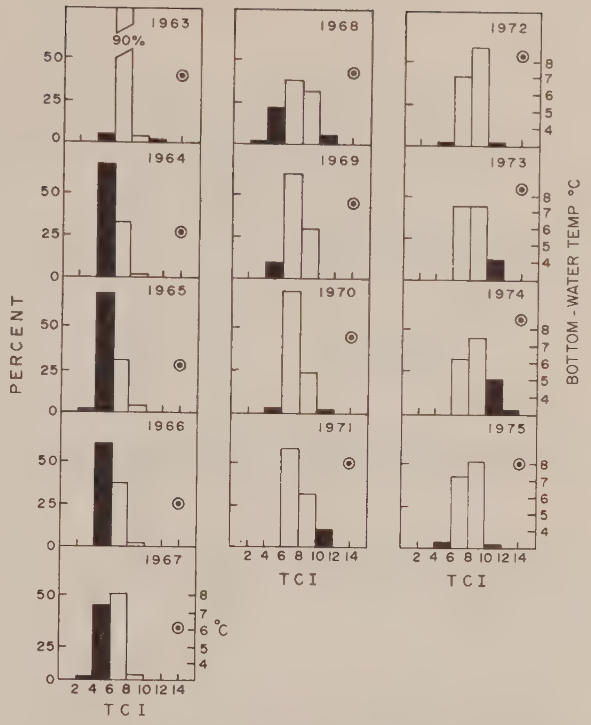


Figure 15.—Percentages of temperature-class intervals (TCI's) in the Gulf of Maine during the autumn, 1963-75. (Dotted circles represent the observed mean bottom-water temperatures.)

Subareas of the Gulf of Maine—Autumn.—Although the adjusted mean bottom-water temperatures fluctuated widely between years, the autumn warming trend which began in 1966 was evident in each of the five subareas (Fig. 16). Temperature peaked at 9.4°C in Subarea I in 1970 and declined quite consistently in subsequent years to a mean index of 7.3°C in 1975; Subarea II peaked at 8.3°C in 1971 and declined to 6.9°C in 1975.

The easternmost subarea (V) was usually the warmest with an adjusted maximum of 10.7°C in 1974 and Subarea II was the coldest with a minimum mean index of 4.6°C in 1966. The largest fluctuations occurred between 1963 and 1964 with decreases up to 2.2°C and between 1967 and 1968 with increases up to 3.2°C. Although Sub-

Table 4.—Mean bottom-water temperatures and anomalies for the Gulf of Maine, autumn 1963-75. Adjusted values are shown in parentheses.

Subarea	Mean	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
I	7.4 (7.5)	+ .9 (+1.0)	- .9 (- .9)	-1.8 (-2.1)	-1.9 (-2.2)	-1.8 (-1.8)	+1.0 (+1.4)	+ .9 (+1.3)	+1.9 (+1.9)	+ .7 (+ .7)	+1.0 (+1.0)	+ .4 (+ .4)	+ .6 (+ .4)	- .9 (-1.2)
II	6.6 (6.6)	+ .2 (+ .8)	-1.5 (-1.4)	-1.7 (-1.9)	-1.6 (-2.0)	-1.1 (- .9)	- .5 (+ .3)	+ .2 (+ .4)	+ .7 (+ .8)	+1.8 (+1.8)	+ .8 (+ .9)	+1.1 (+1.2)	+ .8 (+ .7)	+ .5 (+ .3)
III	6.8 (6.9)	- .1 (+ .5)	-1.7 (-1.2)	-1.0 (-1.3)	-1.5 (-1.8)	-1.1 (- .9)	- .5 (- .4)	+ .3 (+ .4)	+ .4 (+ .4)	+ .8 (+ .6)	+ .9 (+ .8)	+ .9 (+ .8)	+1.5 (+1.3)	+1.2 (+1.0)
IV	7.5 (7.6)	- .5 (0)	-1.5 (-1.2)	-1.7 (-2.0)	-1.1 (-1.4)	- .9 (- .8)	+ .3 (+ .4)	- .2 (- .1)	- .3 (- .3)	+ .2 (+ .1)	+1.3 (+1.2)	+1.1 (+1.0)	+1.8 (+1.6)	+1.2 (+1.0)
V	8.2 (8.2)	-1.3 (- .9)	-1.8 (-1.4)	-1.5 (-1.7)	-1.7 (-1.9)	-1.2 (-1.0)	+1.1 (+1.3)	+ .2 (+ .3)	- .4 (- .3)	+ .3 (+ .2)	+ .6 (+ .7)	+1.8 (+1.7)	+2.6 (+2.5)	+ .8 (+ .7)
Entire Gulf	7.2 (7.2)	- .2 (0)	-1.5 (-1.5)	-1.4 (-1.7)	-1.5 (-1.8)	-1.1 (-1.0)	+ .1 (+ .5)	+ .2 (+ .4)	+ .3 (+ .4)	+ .8 (+ .8)	+1.0 (+1.0)	+1.2 (+1.2)	+1.4 (+1.2)	+ .8 (+ .8)

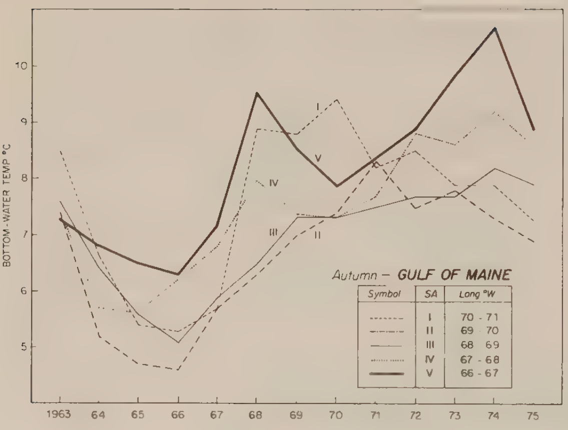


Figure 16.—Adjusted mean bottom-water temperatures in the Gulf of Maine in subareas I-V during the autumn, 1963-75.

area I is the smallest of the Gulf divisions, its large negative anomaly (−1.2°C) in 1975 (Table 4) accounted for much of the decline observed that year for the entire Gulf.

The subarea TCI's shown in Figure 17 are further evidence that years of similar mean temperatures do not necessarily have similar TCI distributions. A good example is shown in Subarea V where the observed means from 1963 to 1967 were all nearly 6.5°C, but the 1963 and 1967 TCI's were vastly different from the 1964-66 TCI distributions. The sharp temperature decline in 1975 in Subarea I was the result of a return of 4°-6°C water that had not occurred there since 1967. The absence of water <8°C in Subareas IV and V was the major factor contributing to the time-series maxima observed for those subareas and also for the entire Gulf of Maine during 1974.

Georges Bank—Autumn.—Autumn bottom-water temperature indices fluctuated widely between years on Georges Bank (Fig. 18) with the two highest adjusted temperatures observed in 1965 (13.1°C) and 1973 (12.7°C); lowest adjusted values were observed in 1967 (10.6°C) and in 1969 and 1970 (10.4° and 10.5°C). The largest annual variations were −2.0°C between 1966 and 1967 and +1.5°C between 1967 and 1968. The 13-yr mean of 11.7°C was about 0.5°C warmer than the 1962-72 long-term mean reported by Karaulovsky and Sigaev (see footnote 2). Data from Schopf (1967) indicate mean autumn Georges Bank temperatures of about 12°C i 1955 and 1961 and 10°C in 1964.

Based on observed means, the two coldest years and 1967) each had about 20% coverage with 4°-6° water, but this was the only similarity of TCI distribution in these years (Fig. 19). The two warmest years and 1974) and several of the intermediate years ha nearly the same TCI distribution. No water >14°C no <8°C was found in the coldest and warmest years, re tively.

Subareas of Georges Bank—Autumn.—Adjuste bottom-water temperatures clearly show that duri autumn Eastern Georges Bank was consistently than the remainder of the Bank by as much as 4°C whil Western and Central Georges Bank alternated as th warmest subarea (Fig. 20). A warming trend for th ter two subareas since 1966 is indicated, but is n vious until 1969 on Eastern Georges Bank. All three subareas exhibited similar increases or decreases of varyin magnitude except when only Eastern Georges Ba creased between 1971 and 1972, and only We Georges Bank increased between 1973 and 1974. Positively adjusted anomalies for each subarea were record 1968 and from 1972 to 1975 (Table 5).

Distributions of TCI's for the subareas of Georg Bank partially explain why the eastern portion was consistently colder than the western or central portions 21). A large proportion of water <8°C occurred i eastern subarea in most years from 1963 to 1971, whil very little water >14°C was found there in any year. Conversely, relatively small amounts of this cold water found in the western or central subareas in any yea water >14°C predominated there in many of the warmes years.

As with the other subareas and other seasons i study area, the distributions of TCI's were not al similar during years of similar observed temperatur means.

DISCUSSION

Annual fluctuations in spring and autumn bot water temperatures in the Gulf of Maine and Ge Bank are obviously related to variations in the volume o relatively cold or warm water which denote change in th composition of these waters. Bigelow (1927) and C (1968b) concluded that the volume and compositi

Table 5.—Mean bottom-water temperatures and anomalies for Georges Bank, 1963-75. Adjusted values are shown in parentheses.

Subarea	Mean	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
Western	12.0 (12.3)	-2.2 (+ .2	-1.2 (- .5)	+ .6 (+ .3)	-1.5 (-1.8)	-3.2 (-1.3)	+ .9 (+ .7)	- .9 (-1.1)	- .2 (- .7)	+1.9 (+1.3)	+1.3 (+ .8)	+1.5 (+ .9)	+2.2 (+1.5)	+ .6 (0)
Central	11.9 (12.3)	-2.7 (- .3)	-1.4 (- .6)	+ .2 (- .5)	- .5 (- .9)	-3.0 (-1.3)	+ .6 (+ .3)	- .2 (- .5)	+ .3 (- .3)	+1.3 (+ .6)	+ .8 (+ .1)	+2.2 (+2.5)	+2.0 (+1.3)	+ .9 (+ .2)
Eastern	9.7 (10.0)	-1.8 (+ .5)	-1.6 (-1.1)	+ .1 (- .5)	- .5 (- .8)	-1.3 (+ .3)	+ .4 (+ .3)	-1.0 (-1.2)	- .7 (-1.1)	+ .3 (- .3)	+ .6 (0)	+2.1 (+1.5)	+2.1 (+1.4)	+1.0 (+ .4)
Entire Bank	11.3 (11.7)	-2.3 (- .5)	-1.3 (+ .4)	+ .6 (+1.4)	- .9 (+ .9)	-2.5 (-1.1)	+ .8 (+ .4)	- .7 (-1.3)	- .2 (-1.2)	+1.1 (0)	+ .9 (- .1)	+2.1 (+1.0)	+1.9 (+ .8)	+ .8 (- .1)

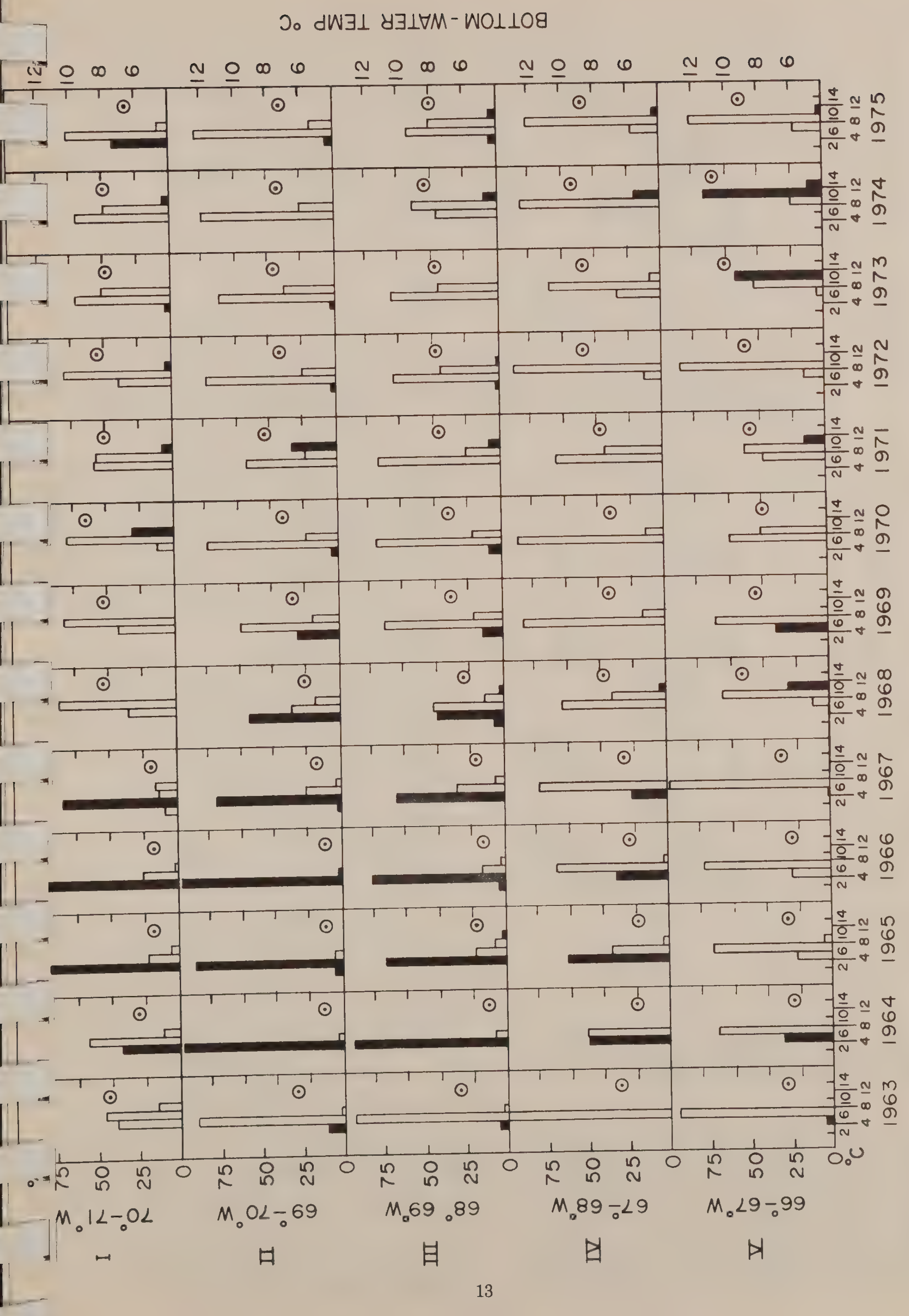


Figure 17.—Percentages of temperature-class intervals (TCI's) in the Gulf of Maine by subareas in the autumn, 1963-75. (Dotted circles represent the observed mean bottom-water temperatures.)

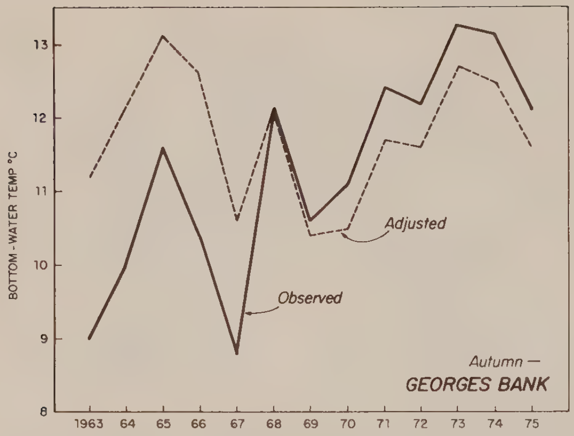


Figure 18.—Observed and adjusted bottom-water temperatures on Georges Bank in the autumn, 1963-75.

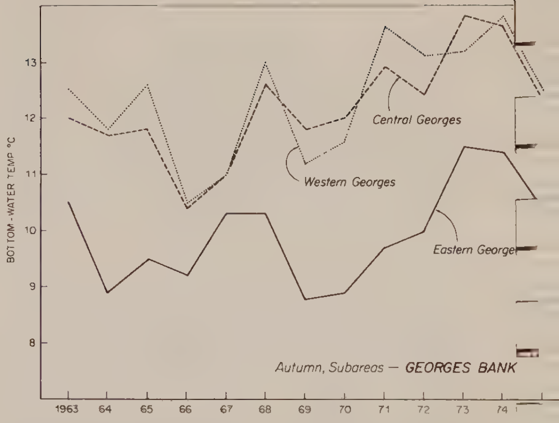


Figure 20.—Adjusted mean bottom-water temperatures on Georg
Bank by subareas in the autumn, 1963-75.

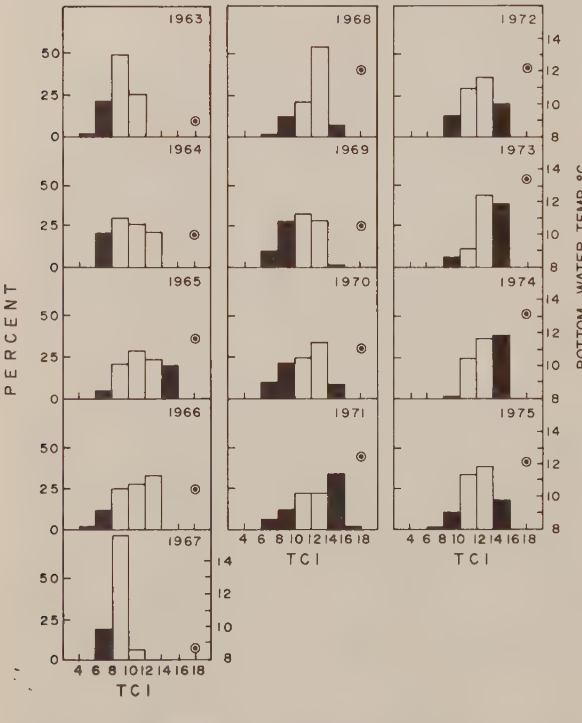


Figure 19.—Percentages of temperature-class intervals (TCI's) on Georges Bank in the autumn, 1963-75. (Dotted circles represent the observed mean bottom-water temperatures.)

offshore waters entering the Gulf of Maine via the Northeast Channel principally determine these variations, at least in deeper basins of the Gulf. Although salinity observations were not analyzed in this study, it can be assumed that fluctuations in the volume of slope water entering the Gulf through the Northeast Channel were mainly responsible for the general temperature trend observed in much of the Gulf and partially affected temperature changes on Georges Bank. Examination of th
continuity of the 8°C bottom isotherm for the sprin
cruises supports this assumption. The high spring
peratures observed in 1972-75 in Subareas IV and V
7) were probably the result of an inflow through th
Northeast Channel each year as indicated by the 8°C iso
therm (Fig. 2). The high mean temperature observ
Subarea III in 1970 was the result of one of two r
large pockets of water >8°C.

It seems clear that anomalous temperature condition
occurred, commencing in the spring of 1970 and au
of 1971, and persisted through 1975. In order to u
stand the dynamics of such changes the National Marin
Fisheries Service initiated in 1977 a program of
tinuous monitoring of temperature, salinity, and
rents in the Northeast Channel and contiguous waters
As stated by Bigelow (1927) this channel is the mos
striking feature of the Gulf of Maine affecting the h
graphy of the region. Also, an examination of avai
data on the volume and location of slope waters (such a
Wright 1976) for waters south of Cape Cod would provid
a better understanding of the observed conditions i
Gulf of Maine and on Georges Bank during this pe

The trend of increasing spring temperatures since 196
is much smoother in the Gulf of Maine (Fig. 6) than o
Georges Bank (Fig. 10) when each area is analyzed
entire unit, but on Georges Bank the subareas are m
more similar within a given year (Figs. 8, 12). This is t
be expected as the waters of Georges Bank are well m
by tides and winds as indicated by the homogenei
TCI's in years of very comparable mean temperature
such as in the spring of 1969 and 1972 (Fig. 11). This con
dition was not observed in the autumn because Eas
Georges Bank was consistently 2°C or more colder
the rest of the Bank. This can partially be explaine
because Eastern Georges Bank, being the deepest of th
three subareas, is least affected by solar heating and
ing. Also, a buffering effect is probably from the in
of cooler slope water through the adjacent Northeas
Channel during the autumn.

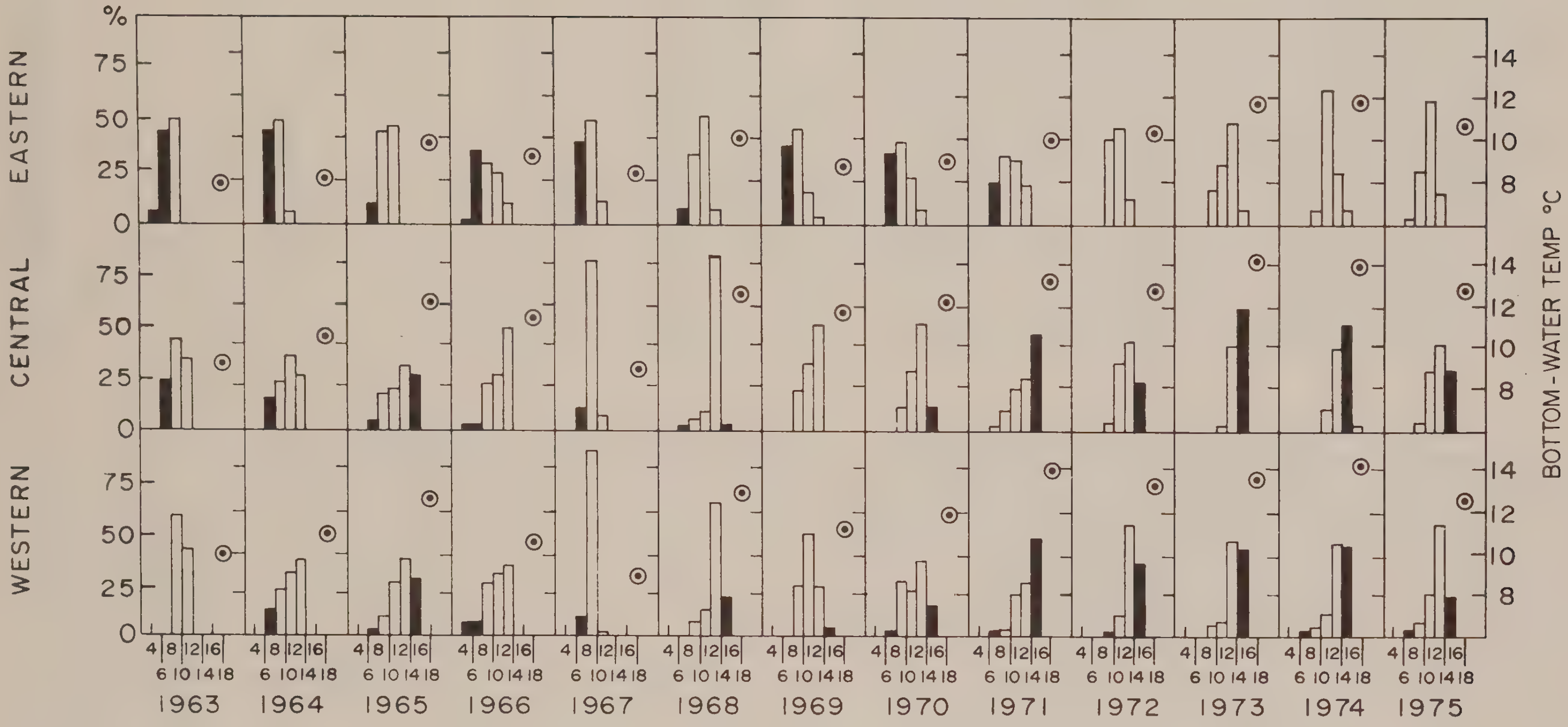


Figure 21.—Percentages of temperature-class intervals (TCI's) on Georges Bank by subareas in the autumn, 1963-75. (Dotted circles represent the observed mean bottom-water temperatures.)

With respect to biological changes, it is perhaps more important to note changes in percentages of certain temperature class intervals rather than variations in temperature means or extremes since the TCI's can be considered areal estimates of suitable habitat for any given species. The reader should again be cautioned that the TCI analysis is intended primarily for comparing habitat conditions at the time of sampling and should not be considered changes between stable annual conditions. Since cruises of some years differed by over a month, and the TCI percentages represent relatively transient phenomena, the value of this analysis is in interpreting how a species may be affected by the observed TCI percentages. For example, during the autumn cruises of 1964-68, relatively large amounts of 4°-6°C water were present in the Gulf of Maine (Fig. 15). These cold conditions were probably quite favorable for northern shrimp, *Pandalus borealis*, in the southern limits of their normal distribution in the western North Atlantic. Both commercial and research cruise indices of shrimp abundance have declined abruptly since 1969 coincident with the rapid decrease and disappearance of 4°-6°C water.

Providing that temperature tolerances or preferences are known for various species, such as that of haddock, *Melanogrammus aeglefinus*, embryos surviving best at about 6°C (Laurence and Rogers 1976), some relationships can be examined. It appears from Clark's[7] data that the year-class strength of 2-yr-old haddock may be related to spawning season temperatures. Since 1968 extremely small year classes have been produced in 2 of the 3 yr that spawning temperatures averaged less than 4.8°C; the two largest year classes were progeny of 5°-6°C temperatures, and temperatures of 6.2°-6.4°C produced intermediate-sized year classes. Unfortunately, these comparisons are available only during a period when the haddock stock and recruitment has been relatively small due to overfishing.

It is unlikely that a simple linear relationship between temperature and spawning success exists, but temperature trends of the magnitude encountered during the past decade undoubtedly influenced certain biological phenomena including changes in spawning time, growth rates, and distributional characteristics of several species. Some notable changes that occurred in this latest warming trend include increased populations of green crabs, *Carcinides maenas*, along the Maine coast (University of Rhode Island[8]); northerly extended seasonal distribution of Atlantic mackerel, *Scomber scombrus*, (Anderson[9]); increased growth rates in the 1970's of Atlantic herring, *Clupea harengus*, (Anthony[10]);
and a general shift of juvenile silver hake, *Merl*
bilinearis, since 1971 from Cape Cod and westw
Georges Bank and the Gulf of Maine (Davis[11]).

Taylor et al. (1957) and Colton (1972) concluded th
there were no general changes in the faunal compc
of the Gulf of Maine during the warming trend of th
ly 1950's nor the cooling period ending in 1966, but th
distributional and spawning habits of several species, i
cluding haddock, were significantly altered. Althc
more complete understanding of the net effects o
perature is required, other gross effects such as tho
stated might be evident if available biological data f
the last decade are closely scrutinized. Certainly,
could be significant value in such correlation analy
time-series data, especially after we have bett
measures of the dynamics involved with tempe
variations in the Gulf of Maine and on Georges

Because of the high variability of bottom-water
peratures between the two major areas and within the
respective subareas during the seasons under stud
important that references to temperature trends be
tified to specific localities and seasons. Contrary to su
references, annual indices of mean bottom-water ter
peratures for Georges Bank and the Gulf of Main
1968 to 1975 are shown in Figure 22. Since only
and autumn data were available, the annual index mu
be considered a gross estimate of average conditions o
served during these years, but the generalized wa
trend shown is nevertheless of value in revealin
changes that have taken place.

Subsequent to the preparation of most of this
script, bottom-water temperature data for 1976 b
available. Preliminary analysis of the data indicat
record high adjusted mean temperatures during t
autumn for both Georges Bank (13.4°C) and the
Maine (9.3°C) and also during the spring in the
Maine (7.2°C). A relatively large inflow of 8°-10°C wat

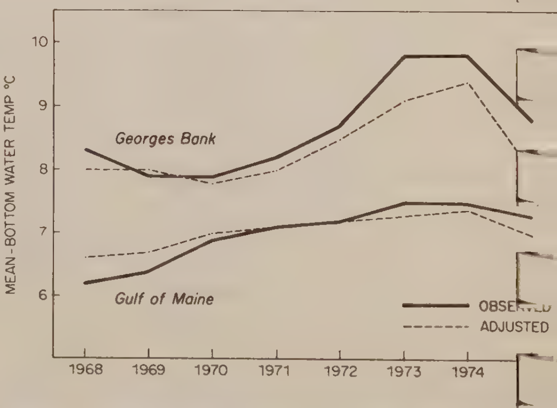


Figure 22.—Annual mean bottom-water temperatures in the Gulf
Maine and on Georges Bank, 1968-75.

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apparently entered the Gulf through the Northeast nel during the spring of 1976.

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hank the many biologists and technicians of the Northeast Fisheries Center (NEFC), National Marine Fisheries Service, Woods Hole, Mass., who collected, zed, and plotted much of the raw temperature Joe Chase of the Woods Hole Oceanographic Institution for providing much of the lightship data; and J. B. Colton, M. D. Grosslein, R. Schlitz, and R. Wright of EFC for reviewing this manuscript.

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NOAA Technical Report NMFS SSRF- 726

The Gulf of Maine Temperature Structure Between Bar Harbor, Maine, and Yarmouth, Nova Scotia, June 1975-November 1976

Robert J. Pawlowski

December 1978

U.S. DEPARTMENT OF COMMERCE
Juanita M. Kreps, Secretary
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Richard A. Frank, Administrator
Terry L. Leitzell, Assistant Administrator for Fisheries
National Marine Fisheries Service

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The Gulf of Maine Temperature Structure Between Bar Harbor, Maine, and Yarmouth, Nova Scotia, June 1975-November 1976

ROBERT J. PAWLOWSKI[1]

ABSTRACT

Monitoring of the temperature structure on a vertical section between Bar Harbor, Maine, and Yarmouth, Nova Scotia, has permitted observation of the seasonal warming and cooling trends in the northern Gulf of Maine. Data have revealed a rise in both temperature and salinity from 1975 to 1976.

INTRODUCTION

ne 1975 the Northeast Fisheries Center and the lantic Environmental Group of the National Marine sheries Service (NMFS) began a cooperative tempera- dy of the northern Gulf of Maine as a part of the ing NMFS Ship of Opportunity Program. Obser- tions were obtained monthly through November 1976, cept for February 1976, aboard the Canadian National s Ferry (C/N), MV *Bluenose*, during its service r Harbor, Maine, to Yarmouth, Nova Scotia. The rpose of this paper is to review and summarize the ta, compare them with historical data, and compare for the summer and autumn of 1975 and 1976.

Long-term and seasonal temperature trends in the lf of Maine have been noted by Bumpus and Chase 967) and Colton and Stoddard (1972). Colton (1968) on a warming trend that reached its maximum m 1952 to 1953, followed by uninterrupted cooling into 67 Davis[2] found an end to this cooling trend in 1968 mption of a warming trend that continued into esent monthly temperature observations show at the warming trend has continued into 1976. The nitoring of these trends is being continued. The area Bar Harbor, Maine, and Yarmouth, Nova was chosen because of the year-round ferry ser- e and our assumption that it gave a representative tion across the Gulf of Maine. Analysis of the circula- he Gulf of Maine (Bumpus and Lauzier 1965; 1967) showed that this section crossed both water Scotian Shelf origin off Nova Scotia and waters mixed h Bay of Fundy to the west. The temperature of water deeper than 150 m represents localized vement in the deep Gulf of Maine and the influence of ters entering through the Northeast Channel.

METHODS

Expendable bathythermograph (XBT) stations were taken at 30-min intervals along the ferry track (Fig. 1) on dates specified in Table 1. Temperature data were collected on a Sippican Model R-603C XBT system, which provided continuous vertical temperature profiling with ±0.2°C temperature and ±0.2% depth accuracy. The recorder was calibrated to specifications prior to each cruise and checked for reference temperature (16.7°C) before each cast. At the station, a sea surface bucket temperature was taken and compared with the recorder surface temperature. Comparison was also made between the ship's bathymetric sounding and the trace bottom mark. As data compared within the system's accuracy, temperatures were read for 0.1°C.

At each station, a sea surface salinity sample was collected for processing ashore on a Beckman Model RS-7B inductive salinometer. The salinometer was calibrated at the beginning and end of each set of samples by water of known conductivity. This method met the manufacturer's specified accuracy (±0.003‰), with data reported to 0.01‰.

Data are presented as vertical temperature sections, sea surface and bottom temperature plots, and sea surface salinity plots. Position data were used in organizing these figures. Each position was determined at sea through Decca radio navigation or radar ranges and bearings on navigational aids or coastal land masses. A standard bathymetric profile was also developed using ship's soundings and the Canadian Hydrographic Office Chart #4011. Temperature was contoured to vertical section for

Table 1.—Dates of expandable bathythermograph observations from MV *Bluenose* between Bar Harbor, Maine, and Yarmouth, Nova Scotia.

18 June 1975	16 Dec. 1976	15 July 1976
16 July 1975	25 Mar. 1976	17 Aug. 1976
13 Aug. 1975	20 Apr. 1976	14 Sept. 1976
17 Sept. 1975	25 May 1976	19 Oct. 1976
14 Oct. 1975	16 June 1976	09 Nov. 1976
18 Nov. 1975		

---

[1] Northeast Fisheries Center, National Marine Fisheries Service, AA, Woods Hole, Mass.; present address: NOAA Ship George B. ez (41), POB 176, Ryder Station, Brooklyn, NY 11234.

[2] avis. 1976. Spring and autumn water temperatures in the ine and Georges Bank, 1968-1975. ICNAF Res. Doc. No. 85, No. 3897, 13 p. Unpubl. manuscr.

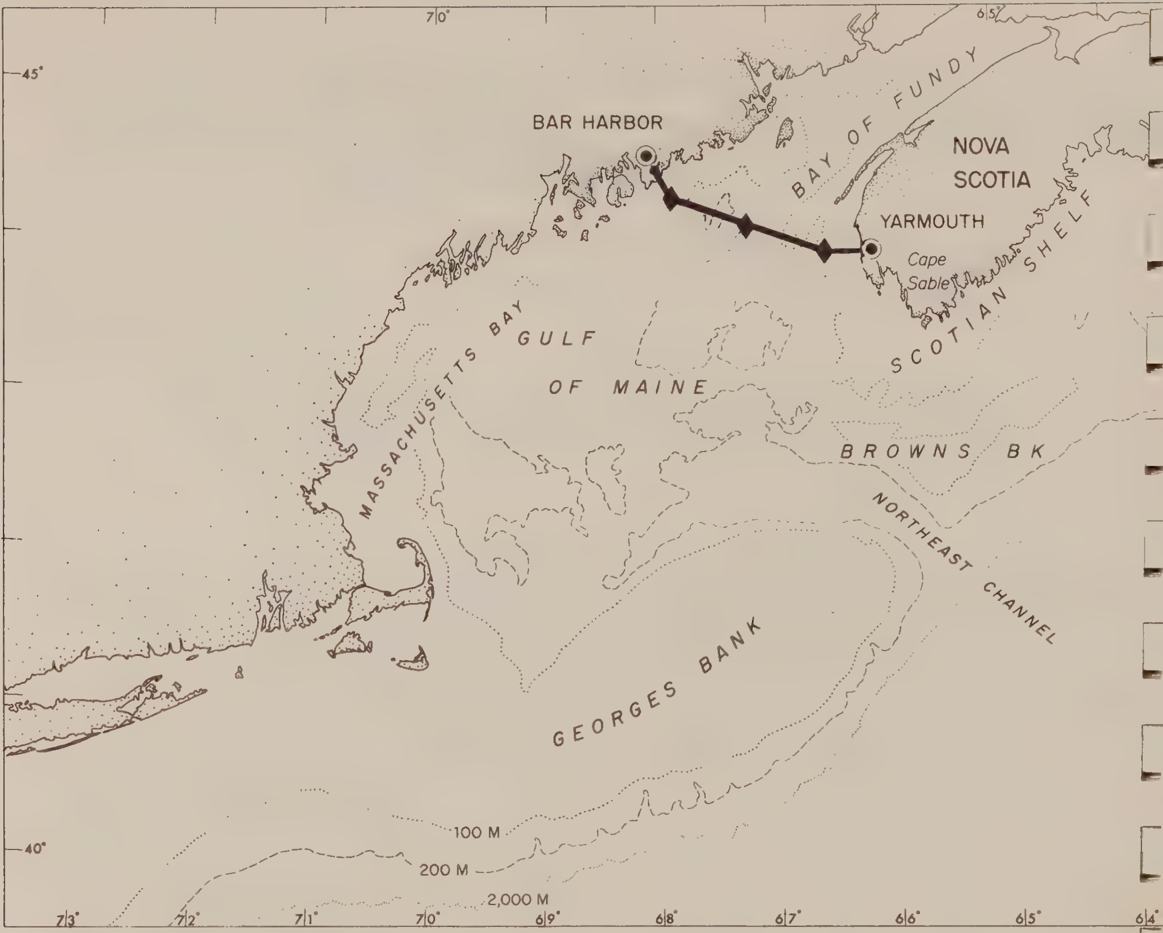


Figure 1.—Location of temperature section monitored by the MV *Bluenose* from June 1975 through November 1976. Positions chosen fo face temperature and salinity and bottom temperature plots are shown along the track. Depth in meters.

1°C intervals, with additional 0.5°C isotherms drawn where appropriate for clarity.

Mean historical sections (Figs. 8-11), taken from Chamberlin et al. (1976), were drawn for each month from horizontal charts based on data collected between 1940 and 1959 for 0 to 100 m (Colton and Stoddard 1972) and on bottom temperature observations between 1940 and 1966 for waters deeper than 100 m (Colton and Stoddard 1973). Data were read from isotherm intersection points along the transect at 0-, 10-, 20-, 30-, 40-, 50-, 75-, and 100-m depths. Linear interpolation was used between the 100-m and the bottom temperature values. Sections were drawn to coincide with sampling dates from 18 June 1975 through 25 May 1976 (Table 1). Many inconsistencies arose due to the scarcity of data for mean sections, as the majority of bottom temperature data were based on a single year's observations (Colton and Stoddard 1973). For such reasons, the mean sections should be used for general comparison only.

Sea surface temperature and salinity and bottom temperatures were plotted against time for three standard locations across the Gulf of Maine (Figs. 12-14); off coastal Maine (lat. 44°15′N, long. 67°58′W), off Nova Scotia (lat. 43°47′N, long. 66°30′W), and center of the Gulf of Maine (lat. 44°00′N, long. 67°16 as shown in Figure 1. As station positions did not coincide with the standard positions, the plotted were determined by linear interpolation for th locations.

RESULTS

Temperature sections were organized by s Summer (June-August), Autumn (September- ber), Winter (December-February), and Spring (Ma May) with mean historical sections similarly arra allow for comparison. The descriptive results we under the appropriate season and year. Analys primarily with the seasonal trends and differences tween summer and autumn 1975 and 1976. Ad analysis was made of the sea surface salinity tre the 18-mo sampling period. The historical sections discussed fully by Chamberlin et al. 1976.

Summer 1975

e temperature structure of summer 1975 (Fig. 2) was characterized by four prominent features: the development of a strong seasonal thermocline above 50 m re of the 100-m isobath, vertical mixing and warming of coastal waters, breakdown of two temperature minimum cells below the thermocline (50-150 m), and minor fluctuation of temperatures in waters deeper 150 m.

Summer solar warming developed a thermocline above 50 m in the central Gulf of Maine, with gradual down- conduction of heat. Above the thermocline waters ed at a rate of about 2°C per month. The maximum surface temperature, 13.6°C, was reached in August, with surface temperatures generally being 1° to 2°C r than in coastal waters (Fig. 2).

stal waters (inshore of the 100-m isobath) warmed throughout the water column, with weak thermocline development off Maine and homogeneous conditions off Scotia. Bottom temperatures reflected the mixing conditions off Nova Scotia, having a greater monthly rise and higher maximum temperature than coastal Maine.

ing June and July two low temperature cells ex- between 50 and 150 m in central gulf waters, bounded by the shallow thermocline and seaward progression of warmer coastal waters. As the season progressed, these cold areas dissipated through warming influence from surrounding layers. A temperature inversion of 1°-2°C occurred below 150 m during June and July with upward mixing that appeared to isolate the shallower cold cells. By August this inversion disappeared and temperatures monotonically decreased to the bottom.

Autumn 1975

Autumn 1975 temperatures (Fig. 3) involved a change from the warming to a cooling trend, with increased vertical mixing. Coastal Maine and central gulf waters began a steady cooling trend in September, while waters off Nova Scotia reached a maximum temperature during September and cooled through October and November. The central gulf's thermocline mixed downward, with continued warming of middepth waters into November. Bottom waters (deeper than 150 m) warmed through September and October, then cooled in November.

Winter 1975-76

The temperature for the winter of 1975-76 (Fig. 4) showed an acceleration in the cooling trend as the largest temperature decrease occurred between December and January (>2°C above 50 m). Minimum temperatures

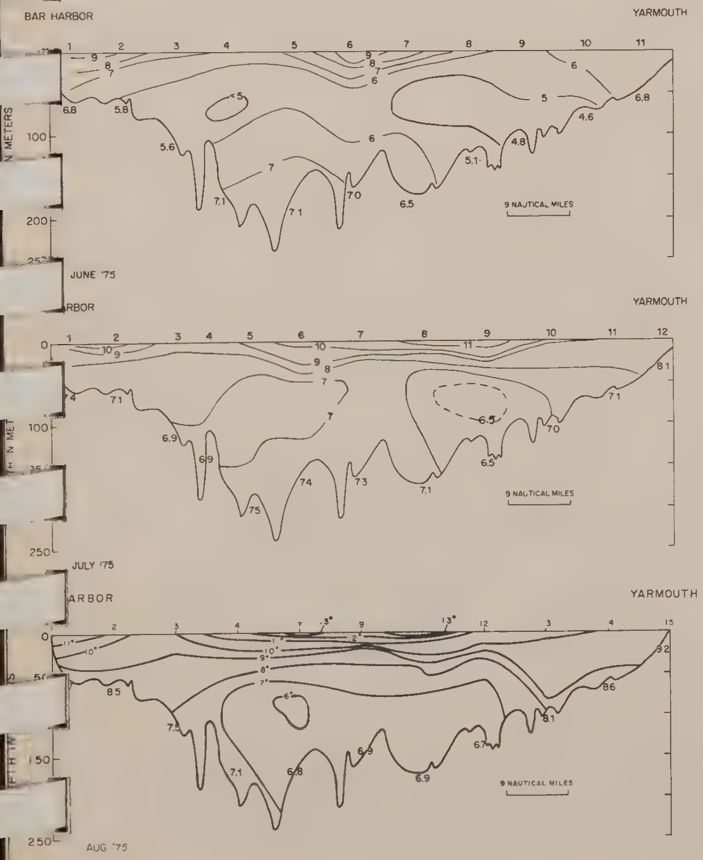


Figure 2.—Vertical temperature sections (°C) for the Gulf of Maine between Bar Harbor, Maine, and Yarmouth, Nova Scotia, summer 1975.

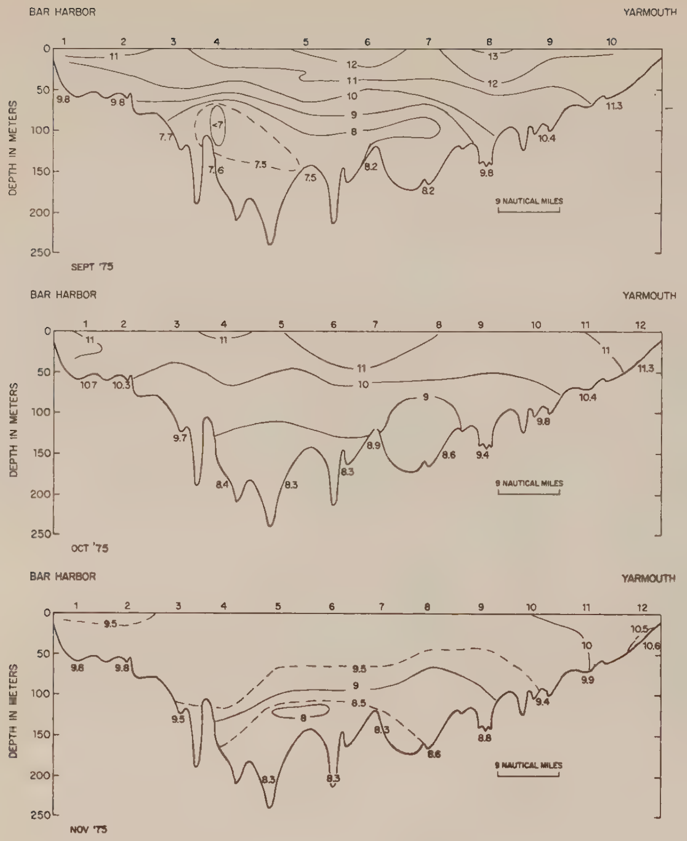


Figure 3.—Vertical temperature sections (°C) for the G of Maine between Bar Harbor, Maine, and Yarmout Nova Scotia, autumn 1975.

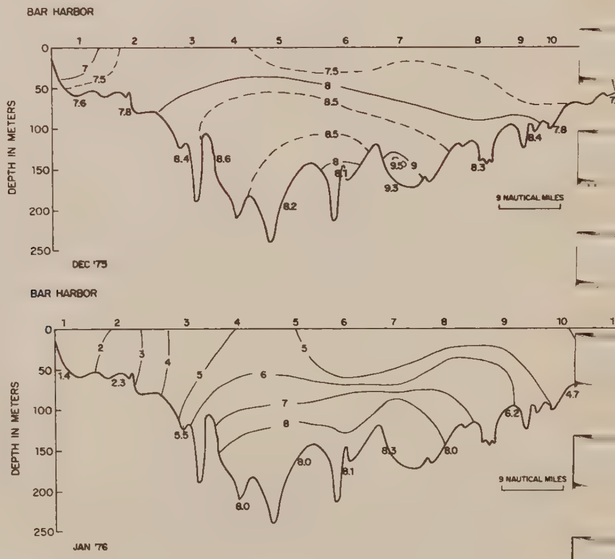


Figure 4.—Vertical temperature sections (°C) for the Gulf of Maine between Bar Harbor, Maine, and Yarmouth, Nova Scotia, winter 1975-76.

were reached in January for coastal Maine and central gulf waters, and in March for Nova Scotian waters (see Figs. 12 and 13). However, due to lack of observations in February, the time for minimum temperatures and reversal to a warming trend could not be accuratel tablished. Below 150 m, a warm cell (>9°C) form eastern basin (Station 7) during December, whi and dissipated by January.

ng 1976

The spring 1976 warming trend (Fig. 5) began in surface waters during March. Minimum temperatures at 50 0 m were reached in March, while waters deeper than 150 m continued a cooling trend until April and May. As the spring progressed, coastal waters warmed from the shores outward, while a thermocline developed e central gulf area above 50 m. These two processes, along with the relatively constant temperature in deep water, constricted the winter-cooled water into a num temperature layer between 50 and 100 m. This was similar to that found in summer 1975 (Fig. 2), but lacked the cellular structure noted previously.

mer 1976

The data from summer 1976 (Fig. 6) showed tempera- haracteristics similar to those of the previous year, but generally 2°C warmer. The thermocline developed through the summer, with rapid surface warming (>2°C) in June and July, followed by a decrease in the warming during August as waters neared maximum temperature. The minimum temperature layer dissipated by July, with continued warming at middepths through st. Temperatures below 150 m warmed into June, ved by a rapid increase in the eastern basin during July and continued increases in both basins through August.

Autumn 1976

Autumn 1976 (Fig. 7) was characterized by a continuation of stable water column conditions and warming into September, with yearly maximum temperatures being 1° to 3°C higher than in 1975. A change to cooling and loss of stability occurred in October with a breakdown of the thermocline. This cooling continued into November bringing temperatures and structure similar to the previous year. Waters deeper than 100 m showed a westerly shift of the 9°C isotherm, but otherwise maintained constant temperatures in September. October followed with cooling and development of an 8°C cell in the western basin. This cell dissipated with an unexplained return to warming in November.

The historical mean data (Figs. 8-13) show the same major features found in the 1975 and 1976 data: the development of a surface water thermocline, the spring-summer minimum temperature layer, and a bottom temperature inversion. Seasonal trends were consistent between historical and present sections. Variations existed in the extent of thermocline development into coastal waters and the change in deep bottom temperature structure. Temperatures were 1° to 5°C warmer in 1975 and 1976 than the mean historical temperatures.

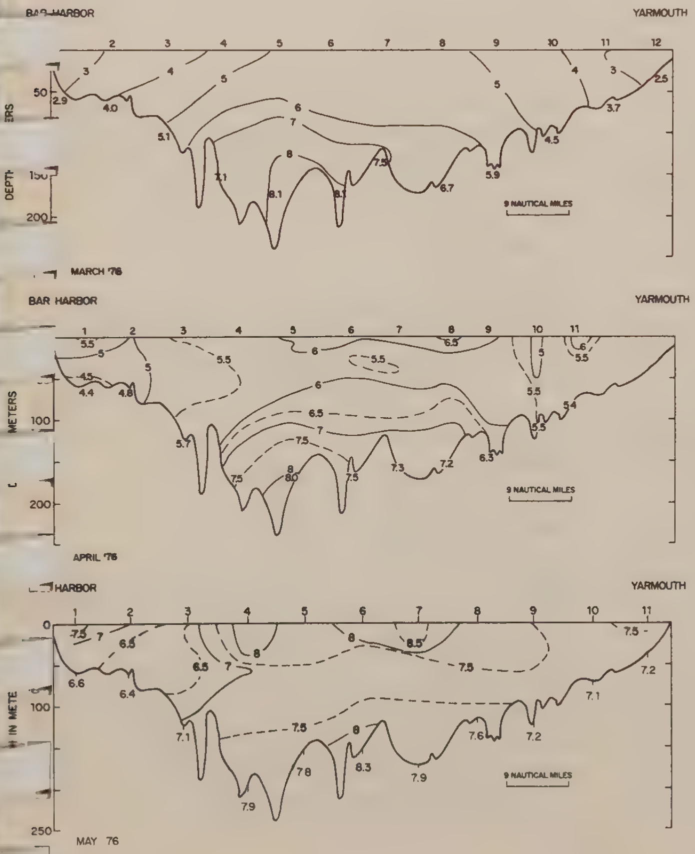


Figure 5.—Vertical temperture sections (°C) for the Gulf of Maine between Bar Harbor, Maine, and Yarmouth, Nova Scotia, spring 1976.

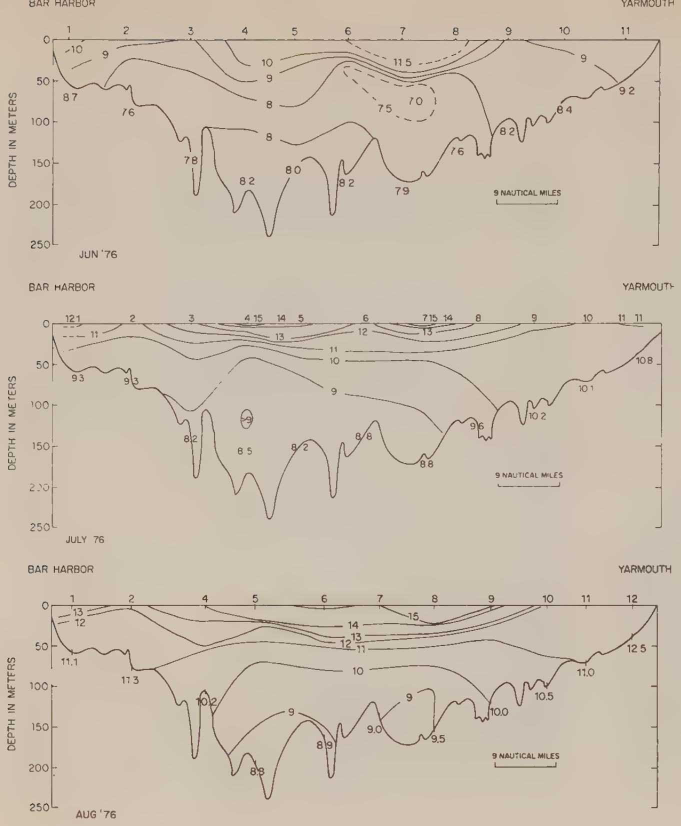


Figure 6.—Vertical temperature sections (°C) for th of Maine between Bar Harbor, Maine, and Yarm Nova Scotia, summer 1976.

The surface salinity (Fig. 14) varied throughout the sampling period with no distinct seasonal characteristics. An overall increasing trend occurred through the sampling period. In most cases, the salinities were higher in the central gulf waters than in coastal waters. The salinity along the study track increased through summer 1975, reaching a peak in October. After October, central gulf and Nova Scotian waters rapidly decreased (0.5‰/month) into November and December, while Maine coastal waters maintained a slower rate. In December the salinity in Maine waters dropped significantly (0.6‰); the lowest values occurred in January, followed by an increase into spring. Both Nova Scotian and central gulf waters maintained a steady increase of salinity through the winter, with peaks in March for central gulf waters and in April for coastal Nova Scotian waters. The gulf waters fluctuated through the spring, with a rise into summer 1976. Salinities continued to increase through the summer and fall, with values about 1‰ higher than in 1975.

DISCUSSION

The Gulf of Maine transect can be divided into five areas: coastal Maine (offshore to 100 m), coastal Nova Scotia (offshore to 100 m), central surface waters (above 50 m), central middepth waters (50-150 m), and centr bottom waters (deeper than 150 m). Each area sh distinct characteristics and interactions with the rounding environment.

Coastal Maine Waters

Coastal Maine waters underwent a warming tre from March through September with development weak thermocline through the summer months. thermocline broke down in the fall, with cooling from shores outward through January. Maximum temper tures were reached in September and minimum peratures in January.

Coastal Nova Scotian Waters

Coastal Nova Scotian waters had homogeneous ditions throughout the sampling period. The warmi trend existed from April through September, with bo tom temperatures 0.5° to 1.5°C warmer than co Maine. The cooling trend proceeded slowly through fall, accelerated through the winter, bringing minimu temperatures by March. The historical means ex similar seasonal development; however, they sh summer thermocline near the Nova Scotian coast w was not present in 1975 and 1976.

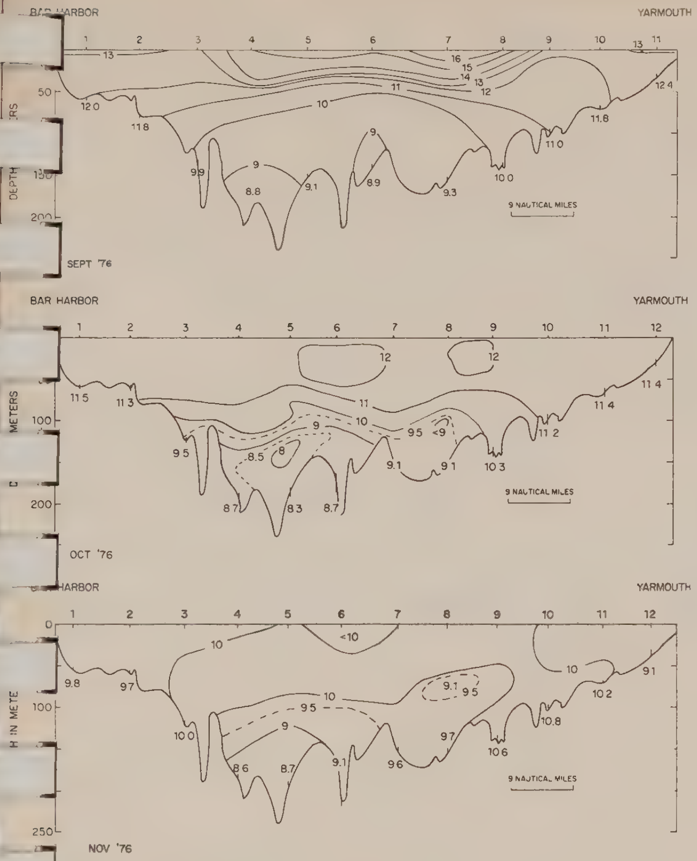
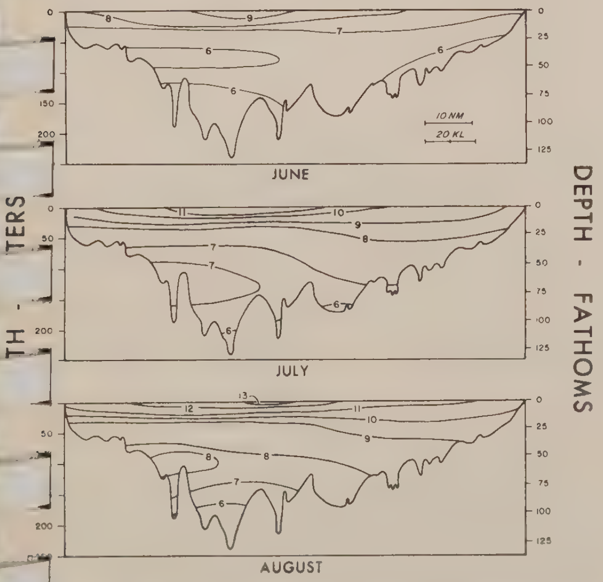


Figure 7.—Vertical temperature sections (°C) for the Gulf of Maine between Bar Harbor, Maine, and Yarmouth, Nova Scotia, autumn 1976.



e 8.—Summer mean temperature sections (°C) (1940-66) for the Gulf of Maine between Bar Harbor, Maine, and Yarmouth, Nova Scotia, from Chamberlin et al. (1976).

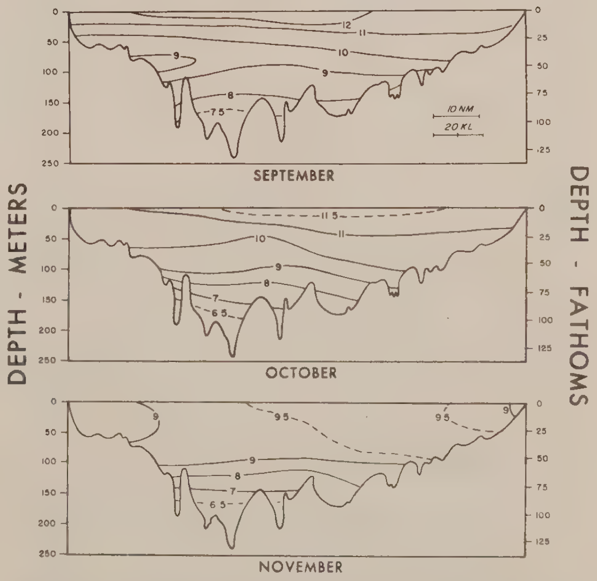


Figure 9.—Autumn mean temperature sections (°C) (1940-66) for the Gulf of Maine between Bar Harbor, Maine, and Yarmouth, Nova Scotia, from Chamberlin et al. (1976).

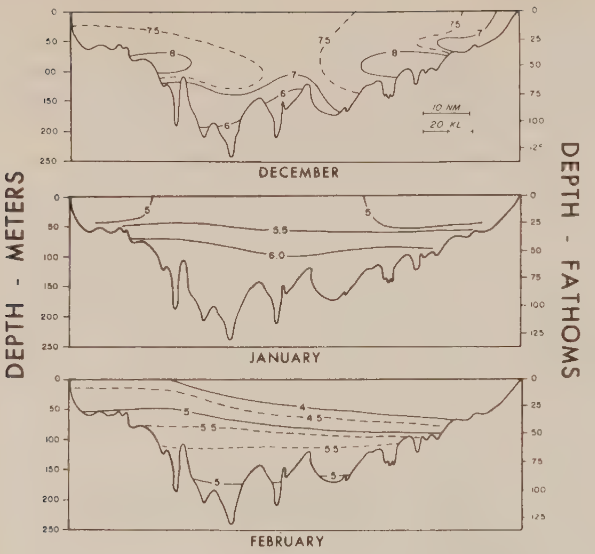


Figure 10.—Winter mean temperature sections (°C) (1940-66) for the Gulf of Maine between Bar Harbor, Maine, and Yarmouth, Nova Scotia, from Chamberlin et al. (1976).

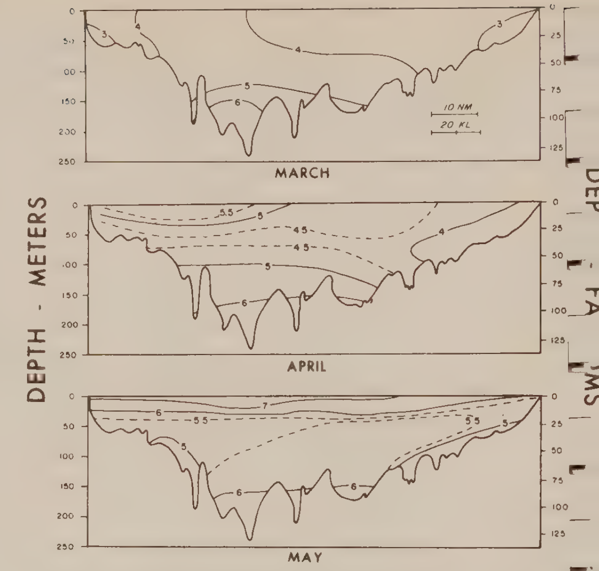


Figure 11.—Spring mean temperature sections (°C) (1940-66) for t Gulf of Maine, and Yarmouth, Nova Scotia, from Chamberlin et a (1976).

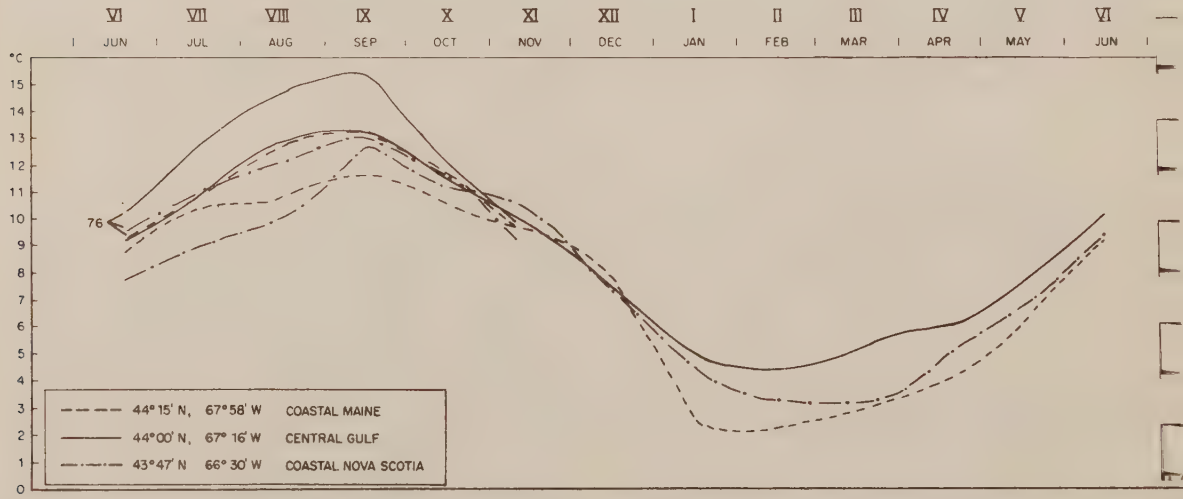
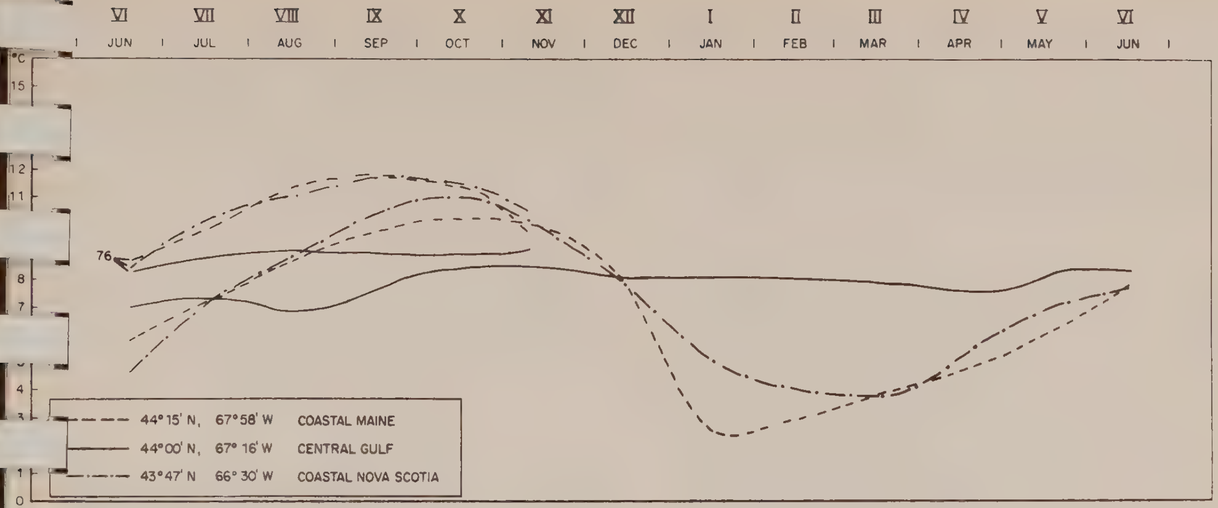


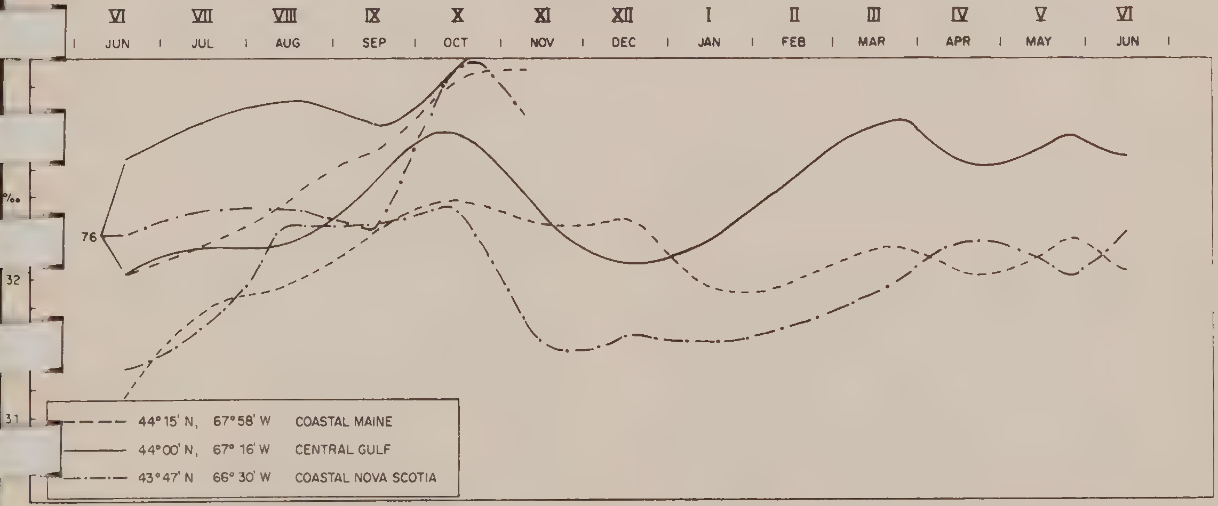
Figure 12.—Sea surface temperature (°C) at three locations (Fig. 1) across the Gulf of Maine, June 1975-November 1976. 1976 Summer an Autumn data indicated by "76".

Central Surface Waters

In the central surface waters the thermocline developed in April and May with warming (>2°C per month) into August. The warming rate slowed in August as temperatures neared the yearly maximum. Maximum temperatures were reached in late August to mid-September, with temperatures 1° to 2°C higher than coastal waters. It is probable that most solar radiation is restricted to heating above the thermocline in this region with little downward mixing by wind or currents. Bumpus and Lauzier (1965) showed the central area to be p of the counterclockwise gyre circulation of the Gulf Maine during summer. Vertical mixing occurred in th autumn with breakdown of the thermocline by Nov ber. Rapid cooling and homogeneous conditions ch acterized the winter, with minimum temperature observed in January. Again, seasonal trends and tem perature structures for 1975 and 1976 were similar historical data, with the exception that minimum te peratures historically occurred in March.



e 13.—Sea bottom temperature (°C) at three locations (Fig. 1) across the Gulf of Maine, June 1975-November 1976. 1976 Summer and Autumn data indicated by "76".



e 14.—Sea surface salinity (‰) at three locations (Fig. 1) across the Gulf of Maine, June 1975-November 1976. 1976 Summer and Autumn data indicated by "76".

ral Middepth Waters

The cooler middepth temperatures found in spring and early summer 1976, summer 1975, and historical spring summer sections, appear to be formed from winter- d water constricted by the offshore progression of warmer coastal waters, the development of the surface th mocline, and the persistence of warmer central bot- waters (>150 m). This layer warmed during summer 1975, and dissipated by August of that year. Warming continued at middepth through October as surface- ned waters mixed downward. A change from warm- o cooling occurred in November with homogeneous conditions developing. This cooling trend accelerated through the winter months, with minimum temperatures occurring during March 1976. As the surface and coastal warming trends began, the minimum temperature layer developed its spring characteristics, with slow warming (1°C per month) into early summer and dissipation by July. The occurrence of this layer in both years and in historical data indicates that it is a characteristic part of the spring temperature structure.

Central Bottom Waters

Waters deeper than 150 m maintained a slow rise (<1°C per month) in temperature, with no seasonal pattern of warming or cooling evident from the data. A lack of seasonal trends was also evident in historical sections.

This is consistent with Colton (1968) in which no seasonal trends were noted for bottom temperatures in the Gulf of Maine. Colton pointed out:

> It would appear that trends in subsurface temperatures can be traced to variation in the composition of these offshore waters as well as to the volume of their indraft through the Northeast Channel.

A review of the sections showed abrupt warming in October and December 1975, and in July and August 1976. These changes are presumably due to influence from mixed slope water. The bottom circulation for the Gulf of Maine inferred from seabed drifters indicates (Lauzier 1967) inflow to this area. However, due to lack of subsurface salinity data, the amount of slope water present cannot be determined. Davis (see footnote 2) noted a bottom-water warming trend from 1971 through 1974, with abrupt cooling by autumn 1975 in the Gulf of Maine. The slow rise in deep temperatures for these sections (Fig. 13) and the differences between 1975 and 1976 for summer and fall temperatures (Figs. 2, 3, 7, 8) indicate fall 1975 as a break in the existing warming trend, followed by a return to warming in 1976.

SUMMARY

All sections showed similar water column structure and seasonal changes when compared to historical sections, but temperatures were generally 1° to 5°C warmer in the 1975-76 sections.

Warming trends began in late winter and continued through summer, progressing from the coast outward in waters inshore of the 100-m isobath. Central gulf waters developed a spring and summer thermocline above 50 m that restricted rapid warming (>2°C/month) to surface waters. Maximum temperatures occurred from late August to September. Cooling trends began in September and October, developed homogeneous conditions by late fall, and cooled through January. Reversal to a warming trend occurred during February to March.

A minimum temperature layer developed in the spring months at middepths with constriction of winter-cooled water by the surface thermocline and offshore progression of warmer coastal waters. This layer continued warming with influence from surrounding layers and dissipated by late summer. The minimum temper layer appeared in 1975 to consist of two cold separated by warmer water. Such structure may related to deep flow into and out of the northern Gulf Maine. Waters deeper than 150 m fluctuated in perature regardless of season, probably due to influ from sporadic slope water inflow at the Northeast Cha nel.

Oceanographic conditions in the Gulf of Maine warmer in 1976 than in 1975. Fall 1976 followed wi cooling that brought similar temperatures for both yea by November. Surface waters in summer and fall were more saline (1‰) than in 1975.

ACKNOWLEDGMENTS

I thank the members of the Atlantic Environm Group for the preparation of historical sections and f assistance in gathering the data. A special word of th is also in order to the officers and crew of the Cana National Ferry, MV *Bluenose*, for their outstanding a sistance throughout this project.

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Expendable Bathythermograph Observations From the NMFS/MARAD Ship of Opportunity Program for 1975

Steven K. Cook, Barclay P. Collins, and
Christine S. Carty

January 1979

U.S. DEPARTMENT OF COMMERCE
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Expendable Bathythermograph Observations From the NMFS/MARAD Ship of Opportunity Program for 1975

STEVEN K. COOK,[1] BARCLAY P. COLLINS,[2] CHRISTINE S. CARTY[3]

ABSTRACT

This report is designed to show the results of the fifth year of operation of the NMFS/MARAD Ship of Opportunity Program (SOOP). The data are presented in the form of vertical distributions of temperature and horizontal distributions of sea surface temperture and salinity. Operational and data management procedures are discussed, and a descriptive analysis of the most dynamic transects showing the Yucatan, Loop, Florida, and Gulf Stream current systems is presented. The annual development and subsequent degradation of the cold cell off the Middle Atlantic Bight is also discussed.

INTRODUCTION

n midyear of 1970, a cooperative expendable bathythermograph (XBT) program was initiated between the National Marine Fisheries Service (NMFS) l the Maritime Administration (MARAD) of the U.S. partment of Commerce. The objective of the cooperative program was to identify and describe seasonal and year-to-year variations of temperature and ulation in the major current regimes of the western pical Atlantic, Caribbean Sea, Gulf of Mexico, and western North Atlantic, utilizing various ships as atively inexpensive platforms for the collection of a.

nnual reports encompassing the calendar year SOOP efforts have been published for 1971 through 1974 (Cook 3, 1975, 1976; Cook and Hausknecht 1977). With the npletion of this 1975 SOOP report the National Oceanographic Data Center (NODC) will publish all future SOOP data, beginning with January 1976, as a ta Availability Notice. The Data Availability Notice l show the monthly transect location of all SOOP runs along with an NODC access number that will allow interested users easier access to the SOOP data.

he program, conducted in support of the Marine sources Monitoring Assessment and Prediction Program (MARMAP) of NMFS, involved the use of ritime cadets from the Kings Point Maritime ademy to collect XBT data on board merchant ships operating along the east and Gulf coasts of the United States. Since 1970 the SOOP program has expanded to lude U.S. Coast Guard cutters and university research sels in addition to regular merchant ships.

Ship routes were selected to obtain regular sampling in the most dynamic areas of the Gulf of Mexico and western North Atlantic. The features of principal interest were the Yucatan Current, Loop Current, Florida Current, Gulf Stream, shelf water-slope water front, and a cold-water cell in the Middle Atlantic Bight.

METHODS

The SOOP effort for 1975 consisted of a total of 65 cruises: 20 merchant vessels sailing from New York, 15 merchant vessels from New Orleans, 19 Coast Guard cruises from various ports, 7 ferryboat cruises across the Gulf of Maine, and 4 cruises utilizing university research vessels. Ninety-eight transects of subsurface temperature observations and associated surface data were obtained. A total of 1,619 XBTs were launched; of these, 1,426 (88%) were considered of sufficient quality to be archived. Approximately 241 XBT drops and associated surface data are not included in this report because the observations were too widely separated in time and space to be formed into useful transects. All data collected were archived by the NODC and are available at the NODC, Washington, DC 20235.

Subsurface temperature data were obtained by use of Sippican XBT systems. At the same time, surface water samples were collected with bucket thermometer units for later analysis to determine salinity. The surface water samples were analyzed on shore using an inductive salinometer calibrated with standard seawater at least once every 30 samples.

The XBT traces were submitted to NODC where they were digitized, key punched, and quality controlled. Finally, these processed data were listed in printout form and machine plotted. The plots produced by NODC were essentially camera ready and needed little hand correcting. The few corrections necessary were caused by anomalous XBT observations that could not be supported by other associated data such as sea surface

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tlantic Environmental Group, National Marine Fisheries Service, AA, R.R. 7A, Box 522-A, Narragansett, RI 02882.

ulf Research and Development Co., Houston Technical Service Center, Box 36506, Houston, TX 77036.

[3] U.S. Dep. Commer., NOAA, Environ. Res. Lab., Room 408, 632 West Ave., Anchorage, AK 99501.

temperature or nearby XBT observations. Consequently, a vertical section plot may have one or two missing observations, resulting from the deletion of inaccurate subsurface data.

During 1975 the data collection program was expanded by the addition of the MV *Bluenose*, an "auto/truck" ferry operated by the Canadian National Railway between Bar Harbor, Maine, and Yarmouth, Nova Scotia. Personnel from the NMFS Atlantic Environmental Group or Northeast Fisheries Center made the observations from the MV *Bluenose* on a monthly basis.

For purposes of consistency with this and past reports, all vertical temperature figures have been organized geographically and chronologically (Gulf of Mexico—January through December, Cape Hatteras—January through December, etc.) and included at the end of the report as appendix figures. Consequently, any particular feature being discussed first may not show up as the first figure within the appendix figures. However, at the beginning of each section that discusses a particular feature, we have listed all figures in the order in which they appear.

For this report all figures have been annotated to show: shelf water-slope water front—SSF; north wall of the Gulf Stream—G.S.; anticyclonic warm core eddy—clockwise circles; cold cell—cc; current flow direction: into the page—circled X, out of the page—circled dot.

RESULTS

Gulf of Mexico Transects

Loop Current.—The 20°C isotherm at 125 m depth has been used in the past as an indicator of the position of the left edge looking downstream of the Loop Current (Cook 1976) and was applied again in this report for consistency. Migrations of the Loop Current edge, along SOOP transects that passed through the Yucatan Straits, ranged from lat. 22°40′N to almost lat. 25°N.

In 1975 the Loop Current was crossed on 11 occasions (see Table 1 and App. Figs. 3, 4, 6, 11, 15, 17, and 21 through 25) by SOOP vessels.

In March the Loop Current was crossed twice by the *Delta Sud*. The two crossings of the Loop Current within 1 mo along the same transect provided the means of calculating the translational speed of the southwar movement of the edge. The *Delta Sud* (App. Fig. 4) crossed the Loop Current at lat. 24°05′N and long. 86°22 on 16 March at 0500 h. The *Delta Sud* (App. Fig. 6) ag crossed the Loop Current at lat. 22°40′N and long 86°15′W on 23 March at 2400 h. The excursion of th northern edge of the Loop Current was 80 n.mi. in 18 or 10.3 n.mi./day (19.1 km/day).

Table 1.—Crossings of the Loop Current made by SOOP vessels in 1975.

App. Fig.	Ship	Cruise number	Station number	Date	Position (lat., long.)
3	*Delta Sud*	75-02	25	2/9-10	23°06′N, 87°01′W
4	*Delta Sud*	75-03	13-12	3/15-16	24°05′N, 86°22′W
6	*Delta Sud*	75-35	13-14	3/23-24	22°40′N, 86°15′W
11	*Delta Norte*	75-05	27-28	5/17-18	22°34′N, 86°26′W
15	*Delta Sud*	75-09	13	9/6-7	24°07′N, 88°58′W
17	*Delta Sud*	75-09	40-39	9/11	24°13′N, 82°23′W
21	*Delta Sud*	75-10	10	10/18-19	24°56′N, 89°43′W
22	*Sea Land Venture*	75-09	29	10/20	26°06′N, 84°53′W
23	*Delta Norte*	75-09	14	10/24	24°18′N, 84°19′W
24	*Delta Sud*	75-10	22-23	11/23-24	24°00′N, 86°33′W
25	*Delta Sud*	75-12	11-12	12/2-3	24°07′N, 88°52′W

Low salinity surface water.—River runoff along Gulf Coast forms a plume detectable by low surf salinities. Utilizing 34.5‰ as the cutoff between coasta and oceanic waters, it was possible to monitor the offshore extent of these low salinity plumes wh sometimes extended to well beyond the shelf break. crossings of low salinity water were detected by SOO vessels in the Gulf of Mexico in 1975 (see Table 2 an App. Figs. 3, 5, 12, 14, 20, and 23). Note that the surf salinities for the *Delta Norte* 75-09 (App. Fig. 18) sho be considered suspect (they are all <34.5‰ while the transect is obviously in an oceanic region). They are cluded in this report because there is no other evidence suggest that the values are false.

Table 2.—Low salinity (<34.5‰) coastal water encountered SOOP vesels in the Gulf of Mexico in 1975.

App. Fig.	Ship	Cruise number	Station number	Date	Estimated offsho exten n.mi. (k
3	*Delta Sud*	75-02	1-2	2/9-10	130 (240)
5	*Delta Sud*	75-35	1-2	3/22-23	80 (1
12	*Delta Sud*	75-07	1-7	7/26-27	180 (3
14	*Sea Land Venture*	75-08	1-3	8/31-9/1	60 (111)
20	*Sea Land Venture*	75-09	1-5	9/28-29	120 (222)
23	*Delta Norte*	75-09	17-16	10/24	150 (2

Eddies.—Analysis of the vertical sections contained in this part shows 11 crossings of eddies or meanderl structures in the Gulf of Mexico by SOOP vessels in 19 (see Table 3 and App. Figs. 3, 4, 7, 10-12, 14, 15, 20, and

Table 3.—Eddies transected in the Gulf of Mexico by SOOP ves in 1975.

App. Fig.	Ship	Cruise number	Station number	Date	Diameter n.mi. (k
3	*Delta Sud*	75-02	14-22	2/9-10	A[1] 175 (324)
4	*Delta Sud*	75-03	18-13	3/15-16	A 215 (398)
7	*Delta Norte*	75-04	8-16	4/6	A 185 (3
10	*Delta Norte*	75-04	33-27	5/11-12	A 94 (1
11	*Delta Norte*	75-05	10-22	5/17-18	A 230 (4
12	*Delta Sud*	75-07	11-17	7/26-27	C[2] 110 (204)
12	*Delta Sud*	75-07	17-21	7/26-27	A 95 (176)
14	*Sea Land Venture*	75-08	17-24	8/31-9/1	C 150 (2
15	*Delta Sud*	75-09	6-12	9/6-7	A 120 (2
20	*Sea Land Venture*	75-09	12-17	9/28-29	C 110 (204)
21	*Delta Sud*	75-10	5-8	10/18-19	C 105 (195)

[1] A = anticyclonic.
[2] C = cyclonic.

21). Unfortunately, the lack of areal detail provided from ngle XBT transect prevents any conclusions ding the formation of eddies from Loop Current meanders. However, for purposes of this report, all of these structures will be referred to as eddies. Eddy ber 1 (App. Fig. 3) was an anticyclonic eddy crossed February and was centered along this transect at station 17 (lat. 25°14′N, long. 89°46′W). A sea surface temperature increase of more than 1°C above the sur- ding water marked the center of the eddy, but no discernible sea surface salinity change was evident. The vertical expression of the eddy extended below 600 m in n.

dy number 2 (App. Fig. 4) was a weak anticyclonic eddy crossed on 16 March and was apparently centered along this transect at station 14 (lat. 24°46′N, long. ′W). The only change in the surface water was an alous decrease in the sea surface temperature. The weak characteristics of this eddy (depth of expression <500 m) suggest that it could have been a frictionally n eddy on the edge of the Loop Current located just of station 13.

Eddy number 3 (App. Fig. 7) was an anticyclonic eddy crossed on 6 April and was centered along this transect at n 12 (lat. 25°39′N, long. 90°09′W). The very slight increase in sea surface temperature indicates that the center of the eddy probably was located somewhat er to the southwest than the subsurface temperature ture indicated. The subsurface vertical temperature structure extended to below 600 m.

Eddy number 4 (App. Fig. 10) was a relatively small yclonic eddy crossed on 11 May and was centered this transect at station 30 (lat. 27°32′N, long. 88°38′W). A slight rise in sea surface temperature, as shown in the surface parameter plot, indicates the eddy nce reached the surface. The bending of the erms was detectable below 750 m.

Eddy number 5 (App. Fig. 11) was a large anticyclonic eddy crossed on 18 May and was centered along this ect at station 17 (lat. 24°57′N, long. 89°19′W). Only a gradual increase in sea surface temperature, peaking in the vicinity of the Loop Current at station 27, gave any ce indication of the eddy location. Monitoring or ing of this eddy would have been difficult without the subsurface information provided by the XBT transect.

dies number 6 and 7 (App. Fig. 12) were crossed on ly and were centered along this transect at station 13 (lat. 26°33′N, long. 91°00′W) and 18 (lat. 25°37′N, long. 89°48′W), respectively. Eddy number 6, because of ss distinct structure and weaker appearance, may been a frictionally driven eddy being forced by eddy number 7, but this was only speculation. Eddy number 7, an anticyclonic eddy, appeared much stronger (vertical erature structure extending to > 700 m) than eddy 6.

Eddy number 8 (App. Fig. 14) was a cyclonic eddy ed on 1 September and was centered along this ect at station 20 (lat. 26°00′N, long. 87°23′W). Very little surface expression in both temperature and salinity showed up on the surface parameter plot. It appeared that intense stratification masked the eddy structure. The subsurface eddy structure began to show in the temperature field at a depth of about 100 m and extended to more than 600 m.

Eddy number 9 (App. Fig. 15) was a weak anticyclonic structure crossed on 6 September and was centered along this transect at station 8 (lat. 25°22′N, long. 90°17′W). No discernible change in sea surface temperature was noticed possibly because of the stratification overlying the eddy structure. Even though the eddy structure was not very dynamic, it was still possible to see the bending of isotherms to below 600 m.

Eddy number 10 (App. Fig. 20) was a cyclonic eddy crossed on 28 September and was centered along this transect at station 15 (lat. 26°41′N, long. 89°12′W). A decrease in the sea surface temperature between stations 12 and 17 indicated that this cold core eddy influenced the surface waters as well as the subsurface water. The vertical extent of this eddy reached > 600 m.

Eddy number 11 (App. Fig. 21) was a cyclonic eddy crossed on 19 October and was centered along this transect at station 7 (lat. 25°51′N, long. 90°36′W). A slight decrease in surface salinity on the southeast edge (station 8) of the eddy was the only surface expression of the eddy's presence. The vertical temperature structure extended to > 700 m. There was no significant change in sea surface temperature in the presence of the eddy.

Cape Hatteras Transects

Gulf Stream.—Gulf Stream crossings were identified by the strong seaward dipping isotherms shown in the vertical temperature sections, and positions of the north wall were determined by using the 15°C isotherm at 200-m depth (Worthington 1964).

In 1975 the Gulf Stream was crossed on 13 occasions (see Table 4 and App. Figs. 27, 29, 31, 33-37, 39-42, and 45) by SOOP vessels in the Cape Hatteras area.

Table 4.—Gulf Stream crossings in the Cape Hatteras area by SOOP vessels in 1975.

App. Fig.	Ship	Cruise number	Station number	Date	Position (lat., long.)
27	*Santa Cruz*	75-01	4-3	1/4	35°08′N, 74°52′W
29	USCGC *Ingham*	75-03	15-14/ 3-2	3/26-27	31°36′N, 71°10′W/ 36°21′N, 72°49′W
31	*Santa Cruz*	75-04	5-6	4/9-10	31°39′N, 78°42′W
33	USCGC *Chase*	75-06	8-9	6/15	36°21′N, 73°40′W
34	USCGC *Chase*	75-65	14-13	6/16	36°21′N, 73°26′W
35	*Trident*	75-07	16	6/24-25	37°56′N, 69°53′W
36	*Mormac Argo*	75-09	10-9	9/8-9	37°07′N, 69°50′W
37	USCGC *Taney*	75-09	4-5/11	9/11-12	36°24′N, 73°17′W/ 36°41′N, 71°30′W
39	*Santa Cruz*	75-09	3-4	9/24-25	33°04′N, 77°27′W
40	USCGC *Ingham*	75-10	5/11	10/2-3	36°19′N, 72°58′W/ 36°58′N, 71°29′W
41	*Santa Cruz*	75-10	2-3	10/29-30	32°10′N, 79°14′W
42	*Mormac Argo*	75-10	9-10	10/31-11/1	36°22′N, 68°21′W
45	*Santa Cruz*	75-12	13-12	12/7	35°41′N, 74°26′W

Comparisons between the SOOP transects, *Gulfstream* monthly summaries (National Weather Service 1975), Experimental Gulf Stream Analysis (N-69) charts (National Environmental Satellite Service 1975), and NAVOCEANO Experimental Ocean Frontal Analysis Charts (U.S. Naval Oceanographic Office 1975) provided a good check on the many fluctuations in the Gulf Stream position.

The XBT transects and the satellite data complement each other in that the XBT data provided the needed ground truth to verify the satellite data, and the satellite data provided the necessary surface synopticity for such a large monitoring program. In addition, the XBT data provided another dimension to the monitoring network in the form of subsurface data. The subsurface data provided the means for monitoring subsurface features such as the "cold cell," the depth of anticyclonic eddies that impinged upon the continental slope and shelf, and the bottom temperatures on the continental shelf that affect many of the commercial finfish and shellfish species.

On 15 June the *Chase* (App. Fig. 33) crossed the Gulf Stream between stations 8 and 9 at about lat. 36°21′N, long. 73°40′W. As usual an increase in the sea surface temperature was noted. An unusual subsurface feature should be noted with this figure. A "bubble" or intrusion of colder water (<8°C) appeared along the edge or north wall of the Gulf Stream at about 100-m depth. This could have been an example of the "calving" process mentioned by Whitcomb (1970) where parcels of the cold cell on the continental shelf appear to break off and detach from the main body of the cold cell and flow seaward off the continental shelf.

In this area around Cape Hatteras three different water masses, shelf, slope, and Gulf Stream water, meet and mix (Fisher 1972). The shelf water mixes directly with Gulf Stream water and in the process pinches out the slope water. One possibility was that the Gulf Stream had moved closer to shore and impinged upon the shelf water mass where the cold cell had formed, and in turn, torn loose a piece of the cold cell and had dragged this cold parcel along the north wall of the Gulf Stream with some colder water reaching the surface. The cold filament mentioned by Fisher (1972) suggests that this could be the mechanism at work here.

Shoreward movement in this area of < 30 n.mi. (55.6 km) by the north wall of the Gulf Stream would be enough for the Stream influence to act upon the shelf water and cold cell. Comparing this XBT transect (App. Fig. 33) with the next (App. Fig. 34) obtained the very next day indicates that translational movements of the north wall of over 10 n.mi./day (18.5 km/day) can occur. What we might have detected was the north wall retreating seaward dragging this parcel of cool water behind it. Examination of the NAVOCEANO Experimental Ocean Frontal Analysis Charts for 9, 11, and 16 June support the contention of a shoreward, then seaward, movement in the north wall on the order of about 10 n.mi./day (18.5 km/day).

The sharp decrease in sea surface temperature (App. Fig. 33) at the shelf water-slope water front (station 7) indicates that the cool filament extended from >100-m depth all the way to the surface.

Another crossing of the Gulf Stream occurred along t same transect only 28 h later (App. Fig. 34). The difference in positions of the north wall crossings was 12 n.mi. (22.2 km), indicating translational movement over 10 n.mi./day (18.5 km/day) which is the same ord of magnitude for translational movements estimated in the past for both the Gulf Stream and Loop Current discussed earlier.

On 30 October the *Santa Cruz* (App. Fig. 41) made t second of two Gulf Stream crossings south of Cape Hatteras. The first was shown in Appendix Figure 31. before, the north wall was so close to the shelf and t scale is so large on these vertical sections that it was difficult to pinpoint the exact position. The crossing of the north wall probably occurred between stations 2 and 3 about lat. 32°10′N and long. 79°14′W. The transition b tween shelf water and Gulf Stream water was so abrupt that the surface parameters only indicated a gradual rise rather than a sharp step increase.

The *Mormac Argo* (App. Fig. 42) crossed through eddy (discussed later) before transecting the Gulf Stream between stations 10 and 11 on 31 October at about lat. 36°22′N and long. 68°21′W. The anticipat increase in surface salinity showed up on the surfa parameter plot and a decrease in sea surface temperature was noted at the point of crossing. The decrease in su face temperature could have been a cold filament simi to those discussed by Fisher (1972).

The last Gulf Stream crossing in the Cape Hatteras area in 1975 was obtained by *Santa Cruz* (App. Fig. 4 on 7 December. Again an eddy was transected prior the crossing, which occurred between stations 12 and 13 at about lat. 35°41′N and long. 74°26′W. On this transect the surface parameter plots of sea surface temperatu and surface salinity show an almost "textbook" examp of the transitions between shelf water, slope water, eddy water, Gulf Stream water, and Sargasso Sea water.

Cold cell.—The formation, structure, and modifi tion of the cold cell that exists on the Atlantic continental shelf between Cape Hatteras and Cape Cod have be discussed for more than 40 yr since Bigelow (1933) Beardsley et al. (1976). Other descriptions of the cold cell hav been given by Ketchum and Corwin (1964) and Whitcomb (1970). Less detailed descriptions utilizi only SOOP data have been given by Cook (1976) a Cook and Hausknecht (1977).

So far the concensus appears to be that the cold cell is formed from winter water on the shelf and that the c cell persists throughout the summer months decreasi in size and extent and increasing in in situ temperature. Some evidence suggests replenishment from the northeast (Beardsley et al. 1976) and that "calving" parcels the cold cell into deeper slope water may contribute the exchange of shelf and slope water (Wright 1976).

In 1975 SOOP vessels transected the cold cell in t Cape Hatteras area on seven occasions (see Table 5 a App. Figs. 28, 32 through 34, 36, 39, and 42).

Table 5.—Cold cell crossings in the Cape Hatteras area by SOOP vessels in 1975.

App. Fig.	Ship	Cruise number	Station number	Date
28	*Santa Cruz*	75-02	4-5	2/19-20
32	*Mormac Argo*	75-03	42-28	5/8-9
33	USCGC *Chase*	75-06	2-7	6/15
34	USCGC *Chase*	75-65	18-16	6/16
36	*Mormac Argo*	75-09	21-17	9/8-9
39	*Santa Cruz*	75-09	2-3	9/24-25
42	*Mormac Argo*	75-10	3-4	10/31-11/1

me of these SOOP crossings show the winter water that eventually forms the cold cell, some show calving, and some show the cold cell extending off the continental .

February, the *Santa Cruz* (App. Fig. 28) crossed through winter water of <5°C near the mouth of Chesapeake Bay. This crossing was important because it s the coldest water crossed by SOOP vessels in the Hatteras area and implies that the cold cell which was formed from this water could not be any colder than that temperature section shows.

May, the *Mormac Argo* (App. Fig. 32) crossed over a ble bubble" of the cold cell. The more inshore bubble had temperatures lower (<7°C) than that of the offsh bubble (<8°C). Because the transect was nearly lel to shore, the "double bubble" could be an artifact of the contouring. Lobes have been detected in the shape of the cold cell, and if a transect crossed through obes, a "double bubble"-like feature would be ined. Two transects in June (App. Figs. 33 and 34), both obtained by the USCGC *Chase,* showed the cold cell well developed with strong stratification above and ore. The 15 June (App. Fig. 33) transect shows a l of cooler water that has "calved" off the main cold cell structure up on the shelf.

Just one day later, on 16 June (App. Fig. 34), almost ame transect as on 15 June was repeated and showed parcel of cooler water that had "calved" off earlier almost totally mixed away.

The close proximity of the north wall of the Gulf Stream to the cold cell and the cold cell parcels warranted a closer look at the satellite imagery in that area for that time period. Examination of the Experimental Ocean Frontal Analysis Charts produced by the Naval Oceanographic Office from 28 May through 16 June of 1975 showed a maximum movement of the north wall 30 n.mi. in 12 days or about 2.5 n.mi./day (4.6 km/day), well within past observations of 10 n.mi./day in the same area. At the same time the Experimental Ocean Frontal Analysis Charts showed a shoreward movement between 28 May and 4 June then seaward movement between 9 and 16 June of the north wall of the Gulf Stream.

As discussed earlier in the Gulf Stream section, the translational velocities of the north wall of the Gulf Stream indicated the possibility that shoreward incursions of the Gulf Stream are large enough in the Cape Hatteras area to act upon the cold cell features on the shelf and possibly pull out parcels of the cold cell.

In summary, we feel that the section obtained on 15 June shows the aftereffects of the shoreward, then seaward, movement of the north wall, where the north wall has acted as the forcing agent in breaking a piece of the cold cell off from the main body and then dragging it seaward as the north wall again moves offshore.

The transects collected in September and October (App. Figs. 36, 39, and 42) show how the cold cell has eroded away throughout the summer. The lowest temperatures in the cold cell were only slightly <9°C in September and slightly <11°C in October.

Shelf water-slope water front.—XBT transects were made across the shelf water-slope water front (SSF) in the Cape Hatteras area on 12 occasions during 1975 (see Table 6 and App. Figs. 27, 28, 30, 34, 36, 37, 41, 42, and 45). Determinations of frontal crossings were made on the basis of subsurface temperature gradients shown on the vertical sections with additional supporting evidence being drawn from sea surface temperature and salinity data.

Table 6.—Self water-slope water front crossings in the Cape Hatteras area by SOOP vessels in 1975.

App. Fig.	Ship	Cruise number	Station number	Date	Rate of temperature change across front computed at maximum thermal gradient
27	*Santa Cruz*	75-01	10-8	1/4	1°C/3.3n.mi. (6.1km)
28	*Santa Cruz*	75-02	10-11	2/19-20	1°C/1.8n.mi. (3.3km)
30	*Santa Cruz*	75-02	18-17	3/30-31	1°C/1.3n.mi. (2.4km)
31	*Santa Cruz*	75-04	2-4	4/9-10	1°C/4.2n.mi. (7.8km)
32	*Mormac Argo*	75-03	29-27	5/8-9	1°C/3.9n.mi. (7.2km)
33	USCGC *Chase*	75-06	7-8	6/15	1°C/2.8n.mi. (5.2km)
34	USCGC *Chase*	75-65	15-14	6/16	1°C/1n.mi. (1.9km)
36	*Mormac Argo*	75-09	17-16	9/8-9	1°C/13.8n.mi. (25.6km)
37	USCGC *Taney*	75-09	1-3	9/11-12	1°C/9.3n.mi. (17.2km)
41	*Santa Cruz*	75-10	1-2	10/29-30	1°C/10n.mi. (18.5km)
42	*Mormac Argo*	75-10	3-5	10/31-11/1	1°C/14.3n.mi. (26.5km)
45	*Santa Cruz*	75-12	21-19	12/7	1°C/8.8n.mi. (16.3km)

Because the SSF is so close to shore in the Cape Hatteras area, and many of the transects ran parallel or at highly oblique angles to the front, the position of the front is not as easily detectable as it is in the Middle Atlantic Bight (to be discussed later). However, a few good examples of the front showing how it develops through late winter and spring should be pointed out.

Santa Cruz (App. Figs. 27 and 28) crossed the SSF right at Cape Hatteras where the shelf water, slope water, and Gulf Stream meet. These crossings that occurred in January and February, respectively, show how the thermal structure develops as the coldest months of winter progress. At this time of the year, when the shelf waters were coldest, the interaction and mixing with Gulf Stream waters created a very distinct thermal front. The *Santa Cruz* (App. Fig. 30) again crossed the front just north of Cape Hatteras (between stations 17 and 18) showing a strong temperature gradient near the mixing region of the three water masses.

Two crossings were obtained in September, one by the *Mormac Argo* (App. Fig. 36) and the other by the USCGC *Taney* (App. Fig. 37). At this time of year the thermal gradient was not as strong as earlier and sea surface salinity was the more accurate frontal indicator.

Also in October the *Mormac Argo* (App. Fig. 42) crossed the SSF in the vicinity of an anticyclonic eddy. The thermal structure of the front was effectively masked by the presence of the eddy and the sea surface salinity values were essential for locating the front.

In December the *Santa Cruz* (App. Fig. 45) crossed the SSF again in the vicinity of an eddy. Although the thermal structure of the front was not as disrupted as in the previous month, it was still necessary to utilize the sea surface salinity as an indicator of the frontal position.

Low salinity surface water.—Utilizing water of <34.5‰ as the boundary between coastal or shelf water and the more oceanic water or slope water, it was possible to monitor positions of the SSF when thermal gradients were mixed or confused. When surface or subsurface temperature data were not available, the 34.5‰ isohaline was used to determine the SSF with confidence. Often when satellite imagery was poor or nonexistent and when temperature stratification was strong, the surface salinity data was the only reliable data available for determination of the shelf water-slope water boundary.

In 1975 SOOP vessels transected coastal water of <34.5‰ in the Cape Hatteras area on 12 occasions (see Table 7 and App. Figs. 27, 28, 30-32, 34, 36, 37, 41, 42, 45, and 46). The data were used independently and sometimes in conjunction with sea surface temperature data to determine the exact position of the SSF.

Table 7.—Low salinity (<34.5‰) coastal water encountered SOOP vessels in the Cape Hatteras area in 1975.

App. Fig.	Ship	Cruise number	Station number	Date	Estim offsh e n.n
27	*Santa Cruz*	75-01	15-12	1/4	55 (
28	*Santa Cruz*	75-02	4-10	2/19-20	5
30	*Santa Cruz*	75-02	31-22	3/30-31	6
31	*Santa Cruz*	75-04	1-2	4/9-10	2
32	*Mormac Argo*	75-03	42-28	5/8-9	50 (
34	USCGC *Chase*	75-65	18-15	6/16	150
36	*Mormac Argo*	75-09	21-16	9/8-9	12
37	USCGC *Taney*	75-09	1-2	9/11-12	8
41	*Santa Cruz*	75-10	1-2	10/29-30	40 (
42	*Mormac Argo*	75-10	1-5	10/31-11/1	250 (
45	*Santa Cruz*	75-12	22-20	12/7	6
46	USCGC *Taney*	75-12	1-2	12/27	8

Eddies.—These XBT sections include only three crossings of Gulf Stream eddies in the Cape Hatteras area during 1975 (see Table 8 and App. Figs. 39, 42, and 45). Eddy number 1 (App. Fig. 39) was an anticyclonic eddy crossed by the *Santa Cruz* on 24 September and was centered along this transect at station 11 (lat. 30°50′N, long. 75°36′W). There was little, if any, sur
expression reflected in the surface parameter plot
Fig. 39) and most of the temperature structure was
beginning about 100 m and becoming stronger at 30
and below.

Comparison with the September 1975 iss
Gulfstream indicated agreement in location with a
cyclonic eddy shown on 10 September.

Eddy number 2 (App. Fig. 42) was an anticy
eddy crossed by the *Mormac Argo* on 31 October a
centered along this transect at station 5 (lat. 37°3
long. 69°55′W). There was a definite increase in sea
face temperature and salinity over the center of th
providing a good signal for satellite imagery. Comp
of this transect with the November 1975 issue
Gulfstream and with the Experimental Ocean F
Analysis Chart for 29 October-1 November 1975 di
good agreement in both the location and areal ext
the eddy.

Eddy number 3 (App. Fig. 45) was a cycloni
crossed by the *Santa Cruz* on 7 December an
centered along this transect at station 16 (lat. 36°
long. 74°18′W). There was definite surface expressio
both temperature and salinity which peaked with
eddy. The decrease in sea surface temperatur
salinity on the southern side of the eddy indicated
possible entrainment of shelf water along its north
and eastern edges. Comparisons made with th
perimental Ocean Frontal Analysis Chart (
December 1975) produced by the Naval Oceanogra
Office agreed well in position and with the poss

Table 8.—Eddies transected in the Cape Hatteras area by S
vessels in 1975.

App. Fig.	Ship	Cruise number	Station number	Date	Dia n.m
39	*Santa Cruz*	75-09	9-13	9/24-25	C[1] 90 (
42	*Mormac Argo*	75-10	4-7	10/31-11/1	A[2] 115 (
45	*Santa Cruz*	75-12	18-13	12/7	A 50

[1] C = cyclonic.

[2] A = anticyclonic.

entrainment of shelf water by the eddy. Also, comparison his XBT transect with the Experimental Gulf Stream lysis N-69 for 4-6 December 1975 produced by the NESS from data obtained from the NOAA-4 satellite thermal infrared VHRR showed good agreement with rd to position and shelf water entrainment.

Middle Atlantic Bight Transects

he Gulf Stream crossings were determined in the e manner as discussed earlier in the Cape Hatteras section, that is, the north wall is located where the 15°C herm is encountered at 200 m. This location is usual- eflected also by increases in surface temperature and salinity. Also the same comparisons between satellite data and XBT data were made as previously discussed.

ulf Stream.—In 1975 the Gulf Stream was crossed on 13 occasions (see Table 9 and App. Figs. 47, 49, 51, 52, 58 through 64, 66, and 67) by SOOP vessels in the Middle antic Bight.

Table 9.—Gulf Stream crossings in the Middle Atlantic Bight by SOOP vessels in 1975.

Fig.	Ship	Cruise number	Station number	Date	Position (lat., long.)
	Mormac Argo	75-03	9-10	3/21-22	37°41′N, 70°19′W
	Export Defender	75-04	10-11	4/27	37°45′N, 67°37′W
51	*Mormac Rigel*	75-05	11-10	5/21-22	38°00′N, 70°58′W
52	*Trident*	75-06	9-10	6/9-11	37°42′N, 69°09′W
	Mormac Rigel	75-08	9	8/16-17	37°28′N, 70°29′W
	Mormac Argo	75-99	14-15	9/20-21	37°20′N, 69°32′W
	Export Defender	75-08	16-15	10/1-2	38°21′N, 67°03′W
61	*Mormac Rigel*	75-10	11-12	10/11-12	37°21′N, 70°25′W
62	*Export Defender*	75-10	15-16	10/17-18	37°42′N, 68°19′W
	Santa Cruz	75-09	31-30	10/19-20	35°26′N, 74°43′W
	Mormac Argo	75-99	30-29	10/22-23	37°50′N, 70°27′W
66	*Trident*	75-12	6-5	12/9-10	38°02′N, 68°30′W
67	*Export Defender*	75-10	32-31	12/11-12	37°02′N, 71°22′W

old Cell.—The importance of the formation, structure, and modification of the cold cell was discussed earlier in the Cape Hatteras section and will not be eated here.

n 1975 there were 15 crossings of the cold cell in the Middle Atlantic Bight by SOOP vessels (see Table 10 l App. Figs. 47, 49, 51 through 56, and 58 through 64). ne of these transects were of crossings of winter water and not the cold cell feature, but were included in the cold cell section because of the importance of the winter er to the minimum temperature of the cold cell.

or purposes of discussion, nine of these observations that have occurred in the same geographic area have been grouped into one transect. This track has been ignated the MORMAC transect because it is the k used by Moore McCormack Line ships and closely follows a line between New York and Bermuda (Fig. 1).

igure 1 summarizes the changes in depth and perature that occur in the cold cell throughout the year. The cold cell ranged in depth from a minimum of 40 m to a maximum of 90 m and randomly expanded and contracted its extent over the bottom.

Table 10.—Cold cell crossings in the Middle Atlantic Bight area by SOOP vessels in 1975.

App. Fig.	Ship	Cruise number	Station number	Date
47	*Mormac Argo*	75-03	1-6	3/21-22
49	*Export Defender*	75-04	1	4/27
51	*Mormac Rigel*	75-05	20-16	5/21-22
52	*Trident*	75-06	30-24	6/9-11
53	*Export Defender*	75-04	24-20	6/17
54	*Trident*	75-07	3-12	6/22-23
55	*Lash Atlantico*	75-07	2-13	7/7-8
56	*Trident*	75-07	36-33	7/11
58	*Mormac Rigel*	75-08	1-4	8/16-17
59	*Mormac Argo*	75-99	1-7	9/20-21
60	*Export Defender*	75-08	28-26	10/1-2
61	*Mormac Rigel*	75-10	1-4	10/11-12
62	*Export Defender*	75-10	2-4	10/17-18
63	*Santa Cruz*	75-09	43-38	10/19-20
64	*Mormac Argo*	75-99	40-38	10/22-23

The cold cell consistently warmed throughout the spring, summer, and into early fall when the fall overturn again began to cool the water column.

The random movement of the cold cell across the bottom could be the aftereffect of calving or the interaction with the SSF which, in turn, was responding to Gulf Stream eddies that may have been passing through the slope water adjacent to the MORMAC transect.

In March (App. Fig. 47) the winter water was <6°C between stations 1 and 6 while up on the continental shelf.

In April (App. Fig. 49) the water was well mixed with temperatures <7°C on the shoreward end of the transect. The cell structure was only beginning to form at this time of the year and was evident with the slight stratification of the isotherms in the near-surface water.

In May (App. Fig. 51) the cold cell was well developed. Temperatures at the bottom were still <6°C for the most part. The cell structure was on the continental shelf with a slight extension seaward over the shelf break.

There were three crossings of the cold cell in June (App. Figs. 52, 53, and 54). The first occurred 11 June and showed a well-developed cold cell with minimum temperatures slightly <7°C. The cold cell was well defined because of the strong stratification above and seaward of the cell. The second crossing occurred on 17 June at a more oblique angle to the cell structure, hence the exaggerated cell-like structure in Appendix Figure 53. At this time, the minimum temperature was still slightly <7°C, but there was an increase in temperature at the bottom between stations 22 and 23 which might be accounted for by an intrusion of warmer water from the shoreward side of the cell structure or just the angle at which the cell was transected, possibly along a lobe or meander of the cell. The third crossing occurred on 22 June and was a much more detailed transect. In this transect the entire cell structure has not been transected, but rather only the main core of the cold cell containing the minimum temperature. In this transect, as with the

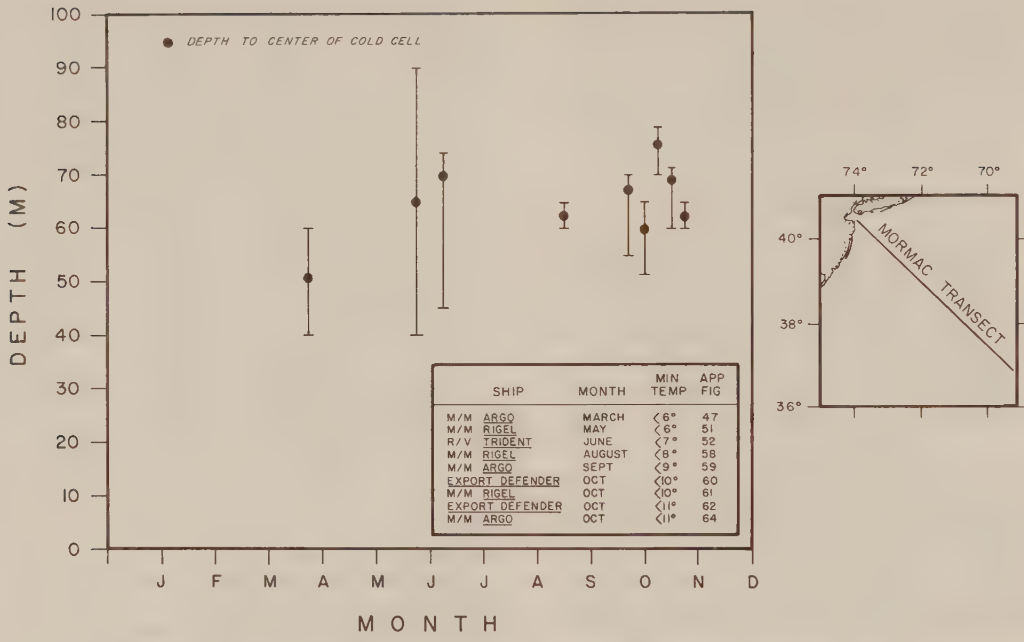

Figure 1.—Variations in cold cell temperature and depth along the MORMAC Transect.

other June transects, the minimum temperatures were slightly <7°C.

In July (App. Fig. 55) the cold cell was well developed and crossed at a nearly perpendicular angle. At this time the cell once again had a "double bubble" shape with the shoreward cell cooler (<8°C) than the seaward cell (<10°C). The cell structure was not as well developed as in May and June suggesting the cell has been eroded away, primarily from the seaward side by slope water as indicated by the warmer cell temperatures there. At this time the minimum temperatures within the cold cell were <8°C. Another crossing later in July by the *Trident* (App. Fig. 56) showed the minimum temperature to have increased to slightly <9°C.

In August (App. Fig. 58) the cell structure extended off the continental shelf break out into deeper water suggesting the possibility of the beginning of the "calving" process. The minimum temperatures within the cell were still slightly <9°C.

In September (App. Fig. 59) the cell structure again extended off the continental shelf into deeper water.

There were five crossings of the cold cell in October (App. Figs. 60 through 64). All transects showed how the cold cell had eroded away. The cell structure was weak at best and all transects showed the minimum cell temperature to be slightly <11°C. The most southern transect (*Santa Cruz* 75-09, App. Fig. 63) showed the minimum temperature in the cold cell to be slightly <9°C. This is consistent with past observations of the cold cell that showed minimum temperatures exist in the New York Bight Apex and just off the New Jersey Coast (Colton and Stoddard 1973).

Shelf water-slope water front.—SOOP transe crossed the SSF in the Middle Atlantic Bight on 20 oc sions during 1975 (see Table 11 and App. Figs. 47 through 53, 55, and 59 through 68).

Determinations of frontal crossings were made, previously discussed, on the basis of subsurface horizo tal temperature gradients shown on the vertical sections with additional supporting evidence being drawn from sea surface temperature and salinity data. To provid means of verification of the position of the front as det mined from SOOP sections, comparisons were made when possible with the *Gulfstream* monthly summa (National Weather Service 1975), the NAVOCEAN Experimental Ocean Frontal Analysis Charts (U.S. Naval Oceanographic Office 1975), and the NESS Experimental Gulf Stream Analysis (N-69) cha (National Environmental Satellite Service 1975).

In general the frontal positions determined from the SOOP transects agreed within ±15 n.mi. (27.8 km) (usually much closer) with the various satellite d sources.

In March (App. Fig. 47) the front was crossed between stations 6 and 8. At this time the remnant winter water of <6°C was still in evidence.

There were three crossings of the SSF in April (Ap Figs. 48, 49, and 50). The 3-5 April crossing (App. Fig. 48) showed the SSF extending well seaward of the 100- depth contour usually associated with the fro Contrasting with this, the 28-29 April crossing (App. Fig. 50) showed the SSF back up on the continental shelf near the 100-m contour. Also with this transect was the ed feature located between stations 25 and 28 (found Bisagni 1976).

Table 11.—Shelf water-slope water front crossings in the Middle Atlantic Bight by SOOP vessels in 1975.

App. Fig.	Ship	Cruise number	Station number	Date	Rate of temperature change across front
47	*Mormac Argo*	75-03	6-8	3/21-22	1°C/12n.mi. (22.2km)
48	USCGC *Evergreen*	75-04	13-15	4/3-5	1°C/3.3n.mi. (6.1km)
49	*Export Defender*	75-04	1-2	4/27	1°C/18n.mi. (33.4km)
50	USCGC *Evergreen*	75-04	28-27	4/28-29	1°C/2.5n.mi. (4.6km)
51	*Mormac Rigel*	75-05	17-16/ 15-14	5/21-22	1°C/6.7n.mi. (12.4km)
52	*Trident*	75-06	24-23	6/9-11	1°C/4n.mi. (7.4km)
53	*Export Defender*	75-04	21-20/ 19-18	6/17	1°C/2.1n.mi. (3.9km)
55	*Lash Atlantico*	75-07	14-18	7/7-8	1°C/11.4n.mi. (21.1km)
59	*Mormac Argo*	75-99	7-10	9/20-21	1°C/12n.mi. (22.2km)
60	*Export Defender*	75-08	23-22	10/1-2	1°C/15n.mi. (27.8km)
61	*Mormac Rigel*	75-10	4-8	10/11-12	1°C/18n.mi. (33.4km)
62	*Export Defender*	75-10	5-6	10/17-18	1°C/9n.mi. (16.7km)
63	*Santa Cruz*	75-09	38-35	10/19-20	1°C/12.5n.mi. (23.2km)
64	*Mormac Argo*	75-99	37-36	10/22-23	1°C/10.7n.mi. (19.8km)
65	USCGC *Bibb*	75-12	1-3	12/5	1°C/4n.mi. (7.4km)
66	*Trident*	75-12	25-19	12/9-10	1°C/5.7n.mi. (10.6km)
67	*Export Defender*	75-10	38-37	12/11-12	1°C/9n.mi. (16.7km)
68	USCGC *Bibb*	75-12	20-19	12/27-28	1°C/3.5n.mi. (6.5km)

e April crossing (App. Fig. 49) was masked by the ea surface temperatures and salinities. The vertical structure of the water column near the 100-m isobath was probably an artifact of contouring due to the large sta- separation between stations 1 and 2.

May (App. Fig. 51) the SSF appeared separated. There was a strong surface gradient between stations 14 and 15 associated with low salinities and cooler water, lso between stations 16 and 17 there was a frontal ture near the 100-m isobath which is more usually associated with the SSF. The subsurface frontal struc- was a good example of the early shape and extent of old cell.

In June (App. Fig. 52) the SSF crossing was reflected in a steep increase in both sea surface temperature and ity. Once again a strong surface expression of the was overlying a strong subsurface front and cold cell.

In June (App. Fig. 52) the SSF appeared at two dif- t positions (between stations 18 and 19 and again een 20 and 21). This double crossing of the front probably reflected a small meander in the front.

In July (App. Fig. 55) the SSF surface temperature ex- ion was weak, as is expected in the summer, and the was better reflected in the subsurface temperature structure surrounding the cold cell.

October (App. Fig. 62) the SSF was considerably ger (1°C/9 n.mi. (16.7 km)) than the earlier crossing in October, probably because of increased surface cooling of the shelf waters.

e final October crossing of the SSF (App. Fig. 64) showed the front was weak, but was detected by the steep increase in surface salinity and the large increase in sea surface temperature.

5 December (App. Fig. 65) the front had increased ength (1°C/4 n.mi. (7.4 km)) and also was easily discernible from the large increase in both sea surface temperature and salinity.

On 10 December (App. Fig. 66) the SSF was still strong (1°C/5.7 n.mi. (10.6 km)) and easily evident from the sea surface temperature and salinity plots.

On 12 December (App. Fig. 67) the SSF temperature structure was not as strong as previous crossings and the front was more easily determined by the strong salinity gradient.

The final December crossing of the SSF was made on 28 December (App. Fig. 68). The front was particularly strong (1°C/3.5 n.mi. (6.5 km)) and was readily discernible by the large increase in sea surface temperature and salinity.

Low salinity surface water.—As previously discussed in the Cape Hatteras section, the utilization of the 34.5‰ surface isohaline as the salinity boundary of the shelf water-slope water has worked well in the past, corresponding closely with the temperature increase usually associated with the slope water.

In 1975 SOOP vessels transected coastal water of <34.5‰ in the Middle Atlantic Bight on 19 occasions (see Table 12 and App. Figs. 47 through 57, 59, and 62 through 68). The data were used in conjunction with sea surface temperature data and sometimes independently to determine the exact position of the SSF.

Eddies.—Analysis of the vertical sections contained in this section show five crossings of Gulf Stream eddies within the Middle Atlantic Bight during 1975 (see Table 13 and App. Figs. 52, 60 through 62, and 64). Unfortunately the five crossings were of only two different eddies. Eddy number 1 (App. Fig. 52) was an anticyclonic eddy crossed on 10 June and was centered along this transect between stations 16 and 17 (lat. 39°01′N, long.

Table 12.—Low salinity (<34.5‰) coastal water encountered by SOOP vessels in the Middle Atlantic Bight in 1975.

App. Fig.	Ship	Cruise number	Station number	Date	Estimated offshore extent n.mi. (km)
47	*Mormac Argo*	75-03	1-6	3/21-22	100 (185)
48	USCGC *Evergreen*	75-04	1-14	4/3-5	160 (296)
49	*Export Defender*	75-04	1-2	4/27	120 (222)
50	USCGC *Evergreen*	75-04	43-28	4/28-29	175 (324)
51	*Mormac Rigel*	75-05	20-15	5/21-22	120 (222)
52	*Trident*	75-06	30-23	6/9-11	60 (111)
53	*Export Defender*	75-04	24-19	6/17	160 (296)
54	*Trident*	75-07	1-12	6/22-23	
55	*Lash Atlantico*	75-07	1-16	7/7-8	330 (611)
56	*Trident*	75-07	37-33	7/11	
57	*Lash Atlantico*	75-07	40-33	8/8-9	200 (370)
59	*Mormac Argo*	75-99	1-10	9/20-21	170 (315)
62	*Export Defender*	75-10	1-5	10/17-18	105 (195)
63	*Santa Cruz*	75-09	46-35	10/19-20	90 (167)
64	*Mormac Argo*	75-99	42-37	10/22-23	110 (204)
65	USCGC *Bibb*	75-12	1-2	12/5	90 (167)
66	*Trident*	75-12	29-22	12/9-10	90 (167)
67	*Export Defender*	75-10	44-38	12/11-12	105 (195)
68	USCGC *Bibb*	75-12	21-20	12/27-28	90 (167)

Table 13.—Eddies transected in the Middle Atlantic Bight by SOOP vessels in 1975.

App. Fig.	Ship	Cruise number	Station number	Date	Diameter n.mi. (km)
52	*Trident*	75-06	19-14	6/9-11	A[1] 65 (120)
60	*Export Defender*	75-08	22-20	10/1-2	A 80 (148)
61	*Mormac Rigel*	75-10	5-9	10/11-12	A 85 (158)
62	*Export Defender*	75-10	6-9	10/17-18	A 45 (83)
64	*Mormac Argo*	75-99	35-32	10/22-23	A 65 (120)

[1] A=anticyclonic.

70°22′W). The surface expression of this eddy showed as a peak in the sea surface salinity and a steep increase in the sea surface temperature.

This eddy was discussed in detail in the June issue of *Gulfstream* and comparisons made between this XBT transect, the *Gulfstream*, and with the Experimental Ocean Frontal Analysis Chart (18 June 1975) showed quite good agreement in both position and areal extent.

Eddy crossings two through five (App. Figs. 60 through 62 and 64) were all the same anticyclonic eddy. Two of the crossings (App. Figs. 60 and 61) were on the edge of the eddy and two of the crossings (App. Figs. 62 and 64) were closer to the center. From the two crossings that were near the center of the eddy, an estimate of the translational speed of the eddy was possible. The *Export Defender* (App. Fig. 62) crossed the eddy on 18 October and was centered along this transect between stations 7 and 8 (lat. 38°57′N, long. 71°03′W). The *Mormac Argo* (App. Fig. 64) crossed the eddy on 22 October and was centered between stations 33 and 34 (lat. 38°36′N, long. 71°21′W). The distance between the two estimated center points was 25 n.mi. and the time difference was 109 h (Fig. 2). The calculated translational speed was 5.5 n.mi./day (10.2 km/day) which is somewhat higher than

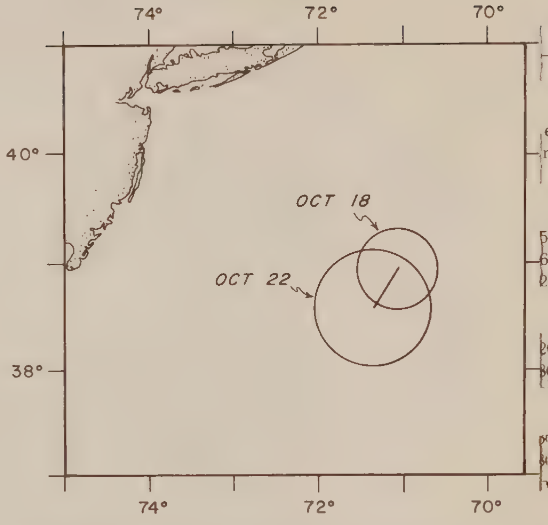

Figure 2.—Distance between the estimated center points of an cyclonic eddy crossed in October 1975.

other translational speed measurements of the sam eddy (Bisagni 1976).

Gulf of Maine Transects

Beginning in June, we began making monthly transects across the Gulf of Maine utilizing the Cana National Railway Ferry MV *Bluenose*. These transects in conjunction with other opportunistic Coast G transects, are employed in the monitoring of the seas variations of temperature in the Gulf of Maine. Thi program is expected to continue into 1976 and 1977 t determine if the Gulf of Maine continues its war trend (Chamberlin et al. 1978).

Brief analyses of these monthly transects were distributed to fishermen and scientists in both the Unite States and Canada, and copies are available from Northeast Fisheries Center at Woods Hole, Mass. A detailed analysis of these transects exists in Chamberli et al. (1978).

Features and conditions looked for in the Gu Maine were slope water and Scotian shelf water influ and general circulation. Slope water is usually identifie by the 9°C isotherm at 200-m depth (Worthington 1 The warmer water that exists in the deeper basins o Gulf of Maine, especially in the winter months, could b attributed to intrusions of slope water through the northeast channel.

Although some transects showed 9°C or warmer w at depth (App. Figs. 76, 79 through 82), without supporting subsurface salinity data, verification that this i due to intrusion of slope water into the Gulf of Mai impossible.

One transect (App. Fig. 76) in particular was rathe striking. In July the USCGC *Evergreen* transected water at depth, north of Georges Bank. This 11°C w was closely associated with the northeast channel even without supporting subsurface salinity data was as- d to be a slope water intrusion into the Gulf of e.

Directly above the warm water intrusion was a strong thermal front extending to >50-m depth and indicating a out of the Gulf. Another thermal gradient existed een stations 1 and 4 indicating a flow into the Gulf from off the Scotian shelf, which is consistent with past vations (McLellan 1954), and is considered to be a ure of St. Lawrence, Scotian shelf water, and surface slope water. The minimum temperature observed along this transect (App. Fig. 76) was <4°C and occurred as an sion at depth and can be attributed to Scotian shelf influence. Earlier in the year the Scotian shelf water influence was much more evident (App. Fig. 74). A tongue of 2°C water at about 50-m depth extended the e length of the transect as far south as lat. 42°27′N long. 65°49′W. At the most northern end of the transect (lat. 43°24′N, long. 64°06′W), 1°C water was also becoming evident.

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Because this is the last of these SOOP reports to be published by NMFS, it is appropriate to acknowledge all people involved with preparation of this and past P reports. Appreciation for the many typings of the many manuscripts is given to Gertrude Kavanagh, Jennie Dunnington, Judy Cichy, Lynn Howell, and Susan hardt. Deep and imbuing gratitude to Lianne strong for her many hours of layout and drafting services patiently provided over the years. Approbation is also given to Reed Armstrong for his assistance and iled examination of many of the Gulf of Mexico transects.

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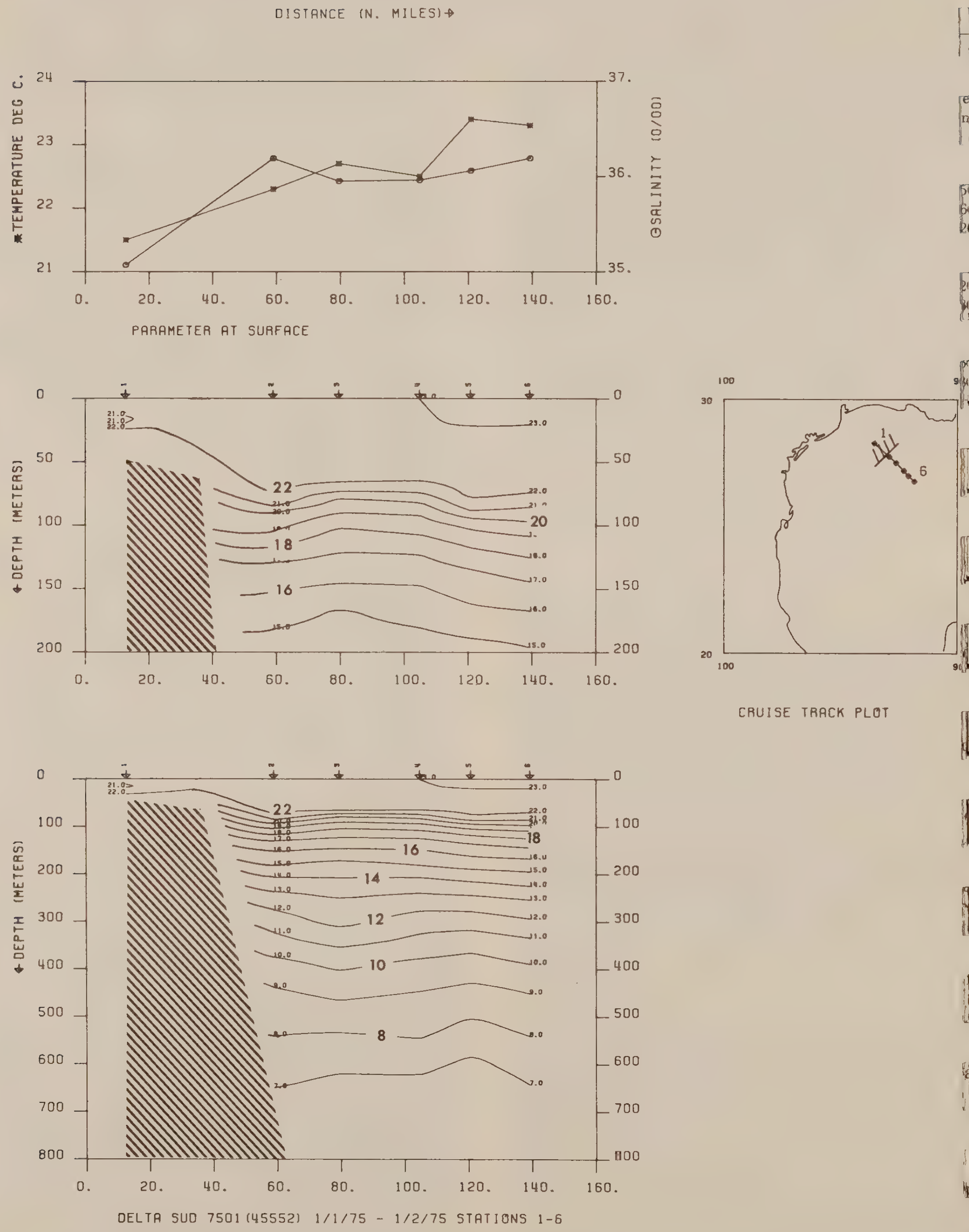
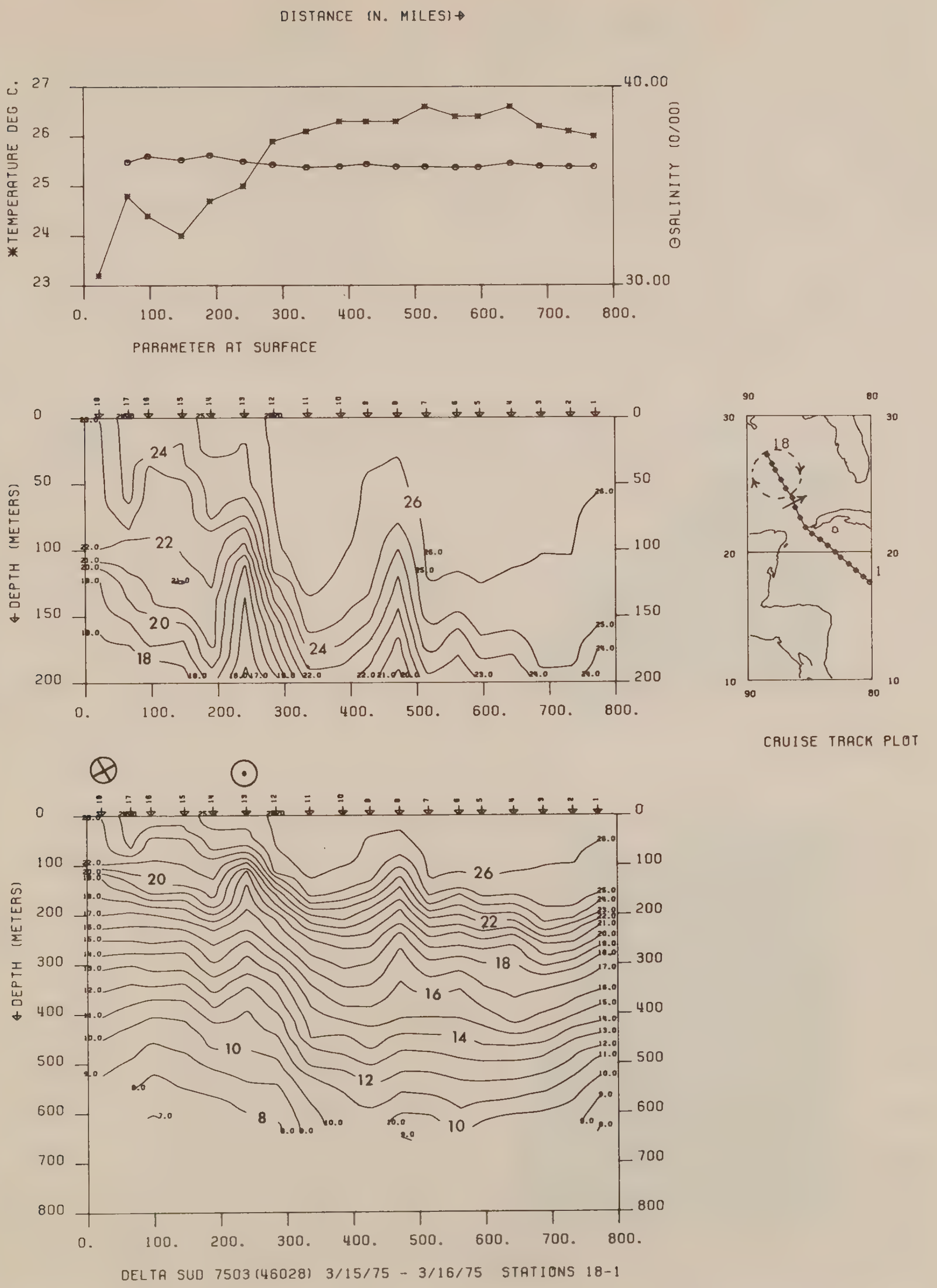
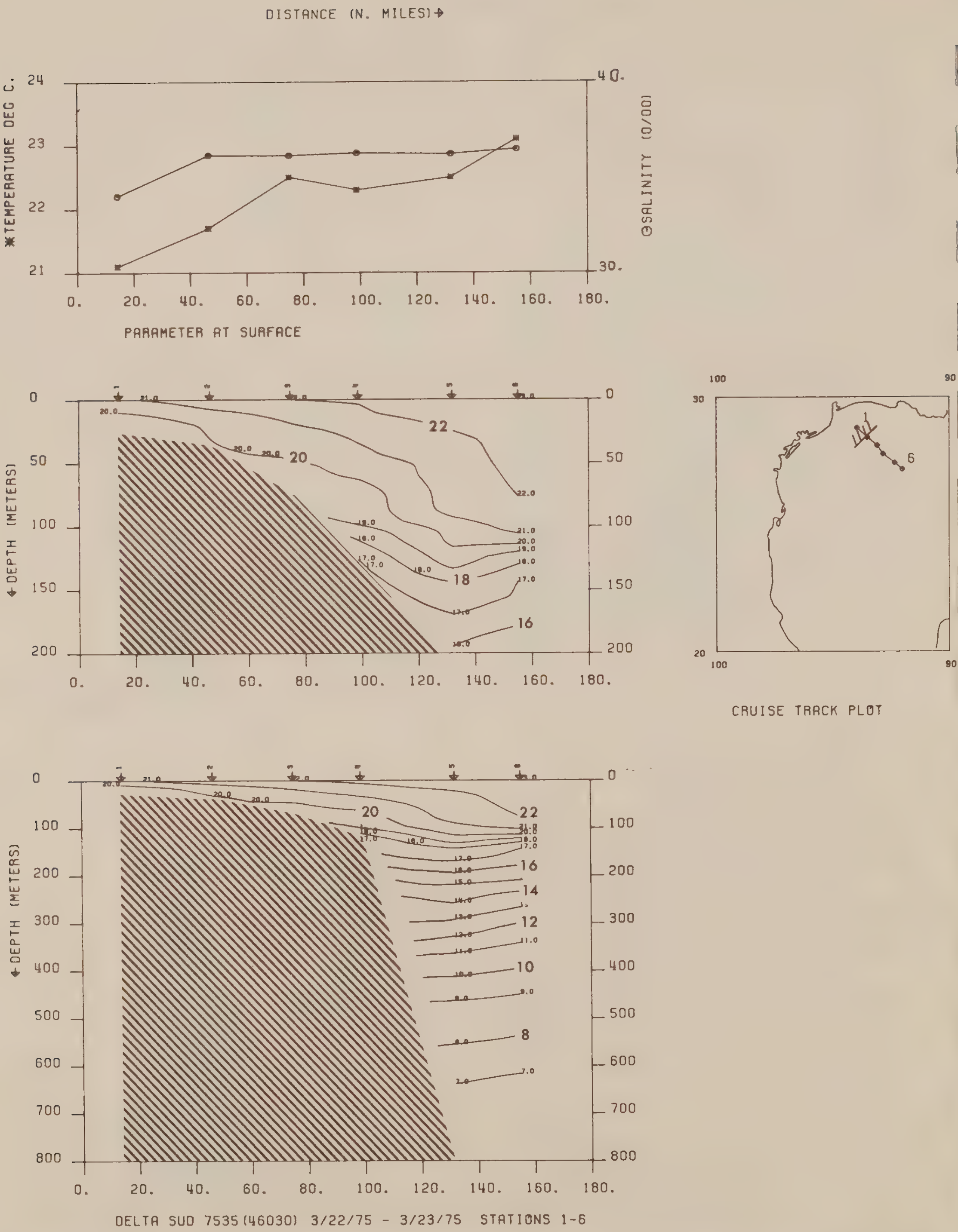
GULF OF MEXICO TRANSECTS



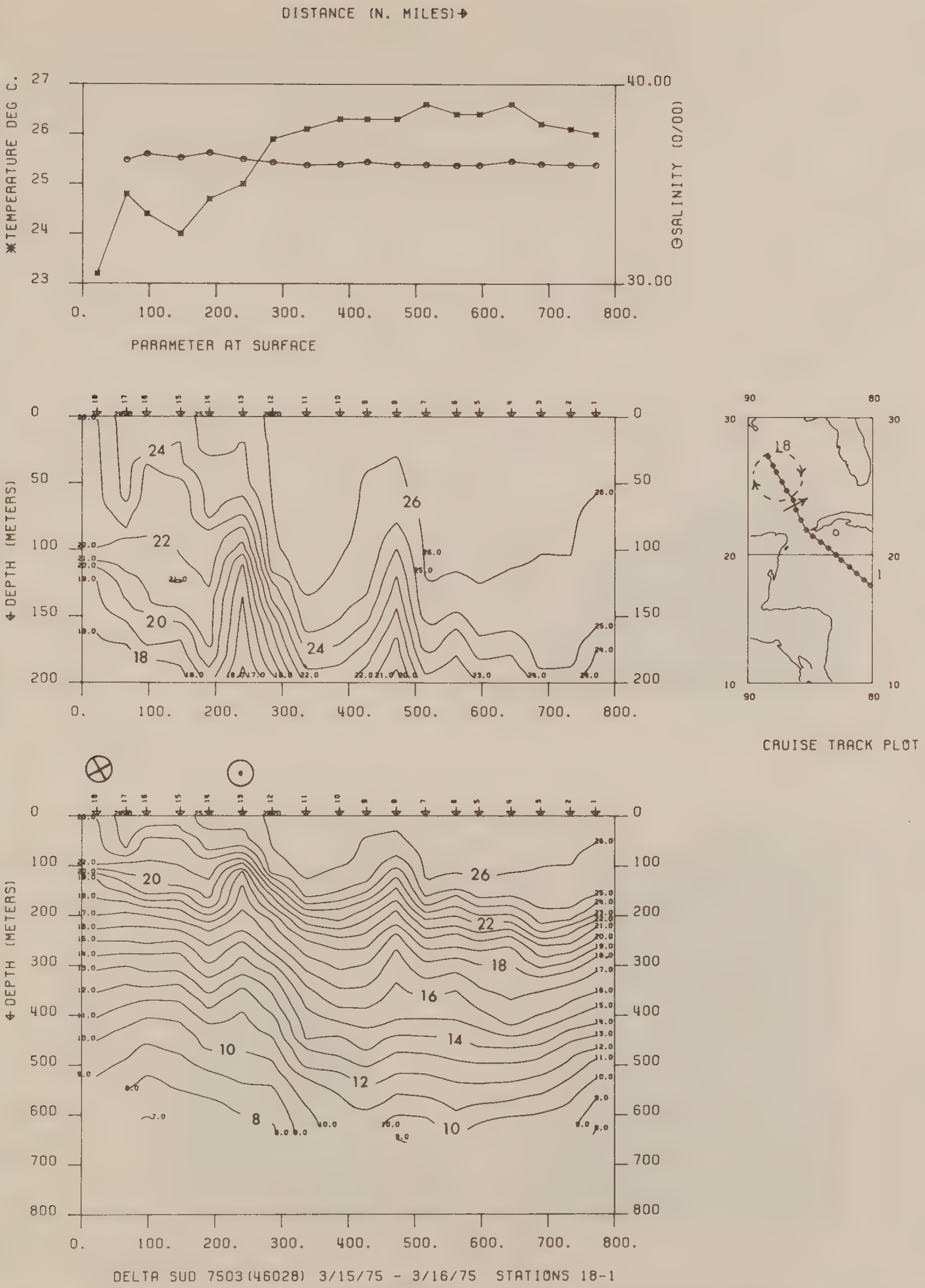
Appendix Figure 1.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distributi of temperature (°C) in the upper 200 and 800 m. *Delta Sud*—1-2 January 1975.



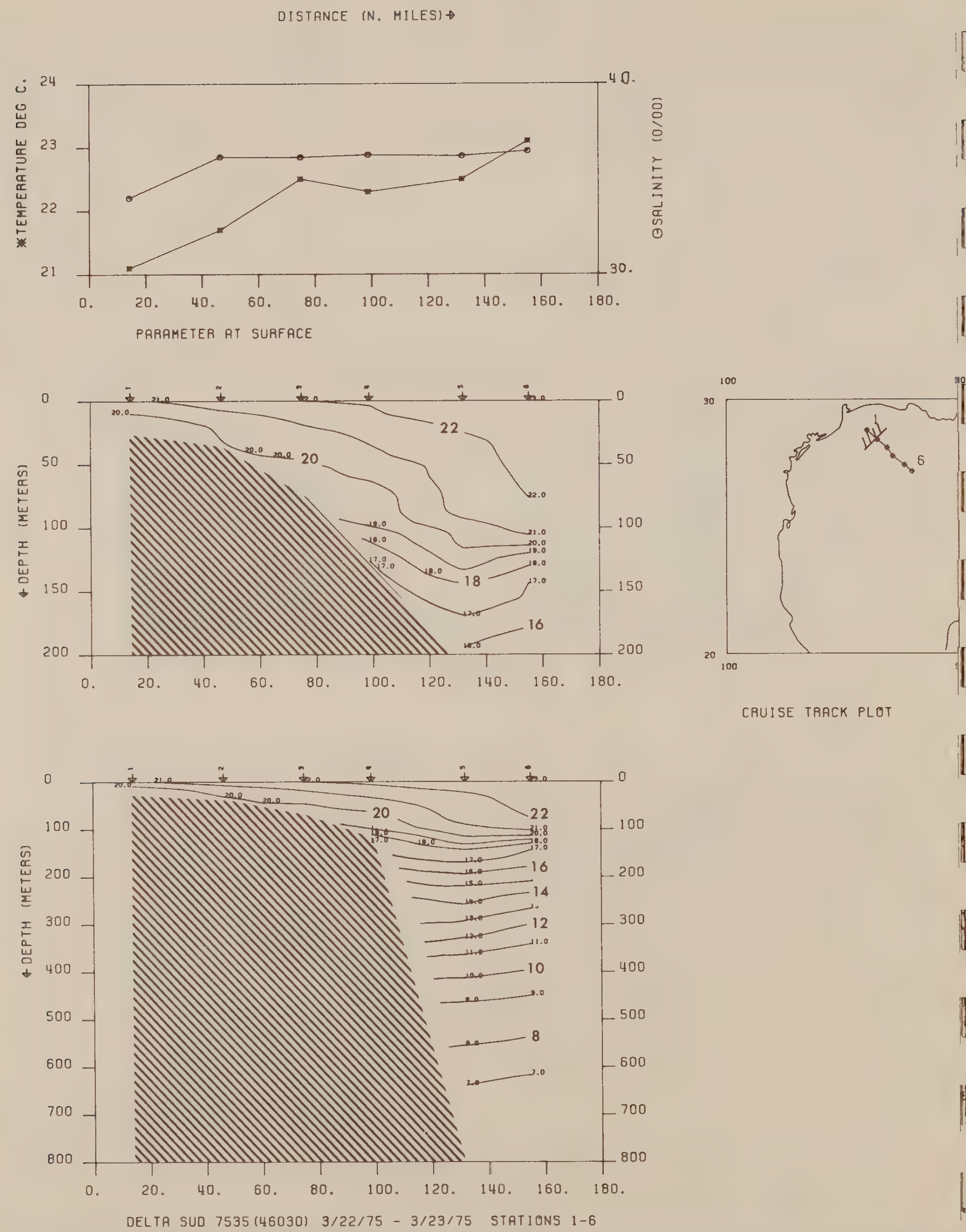
Appendix Figure 4.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Delta Sud*—15-16 March 1975.



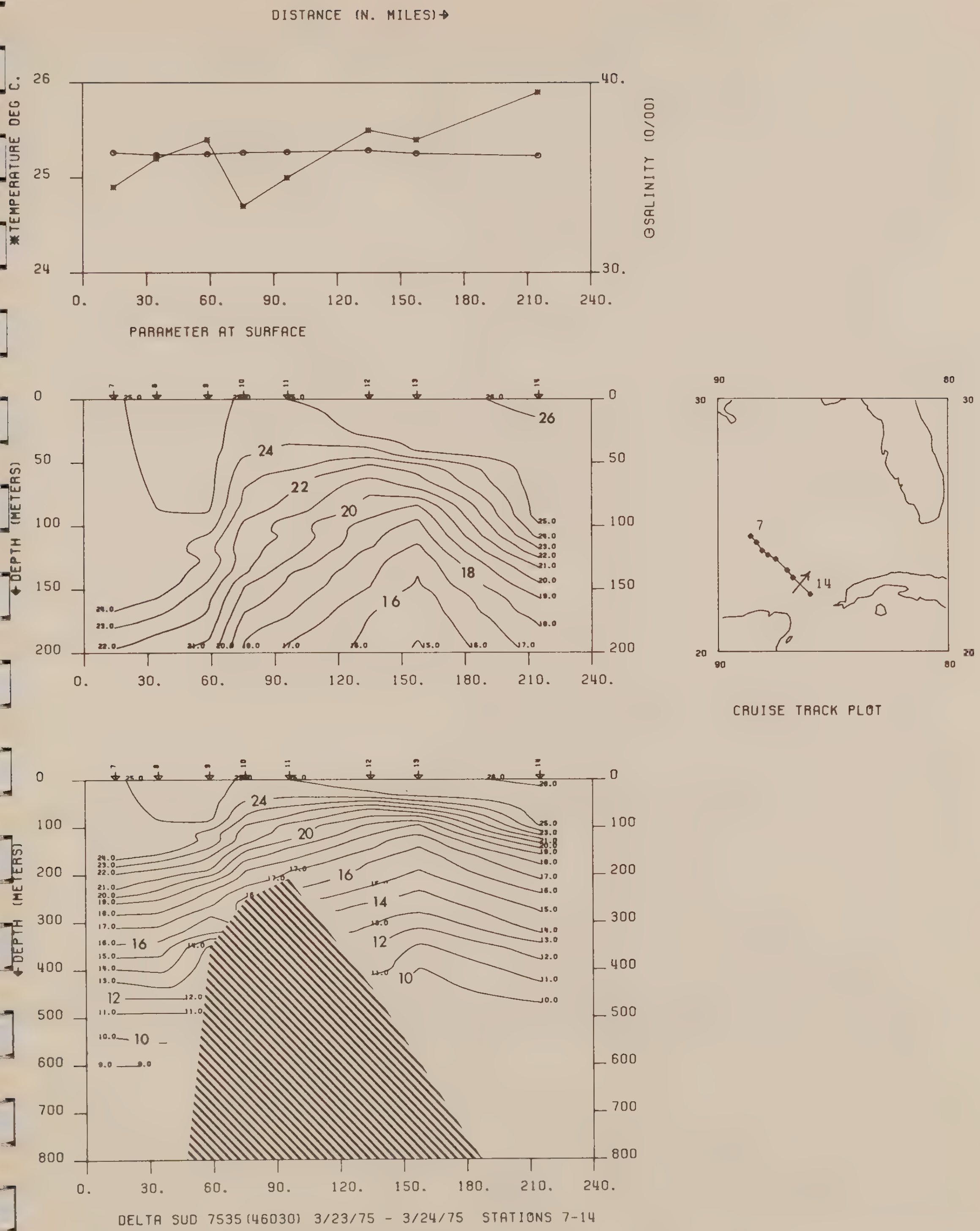
Appendix Figure 5.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Delta Sud*—22-23 March 1975.



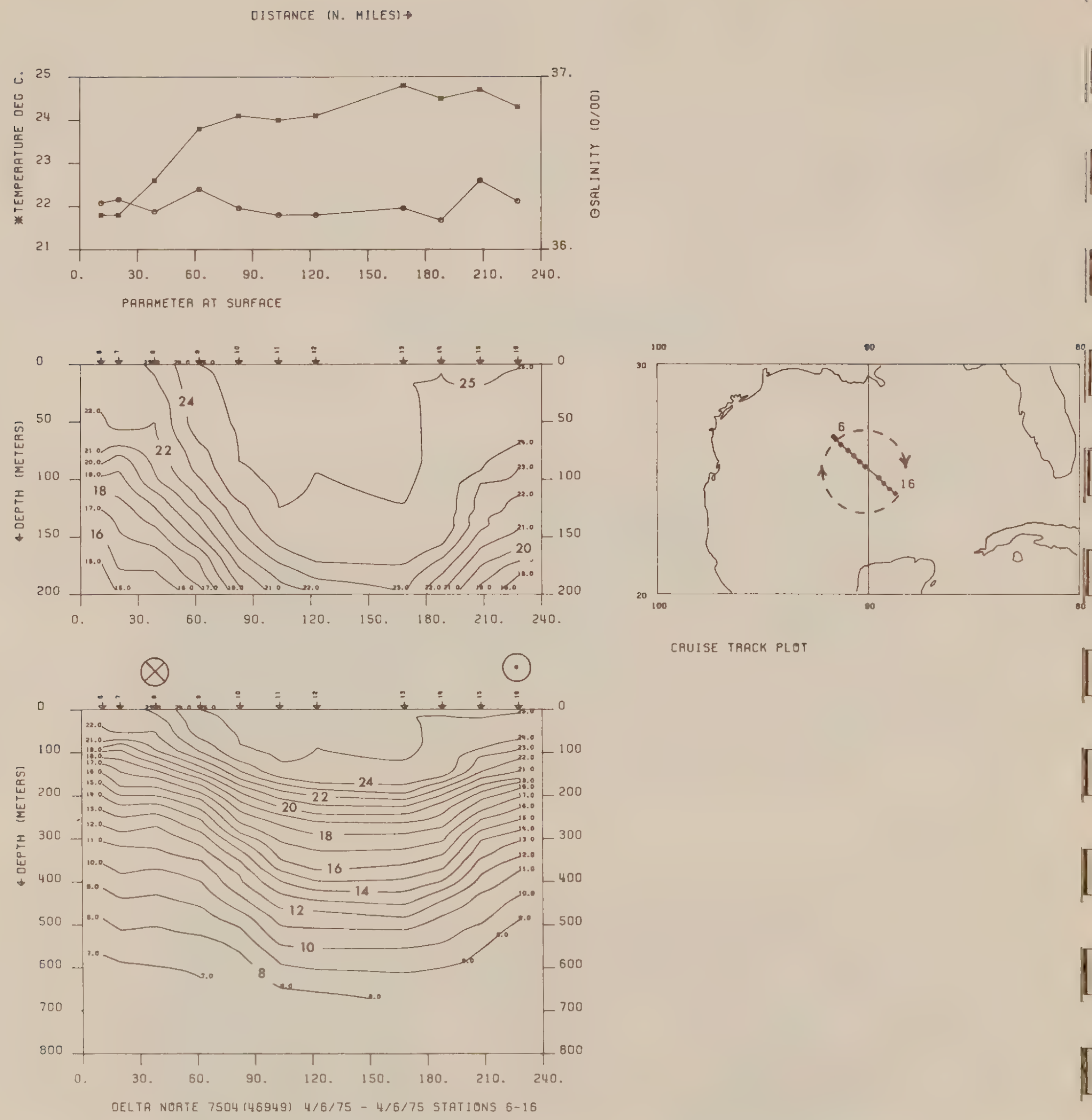
Appendix Figure 4.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Delta Sud*—15-16 March 1975.



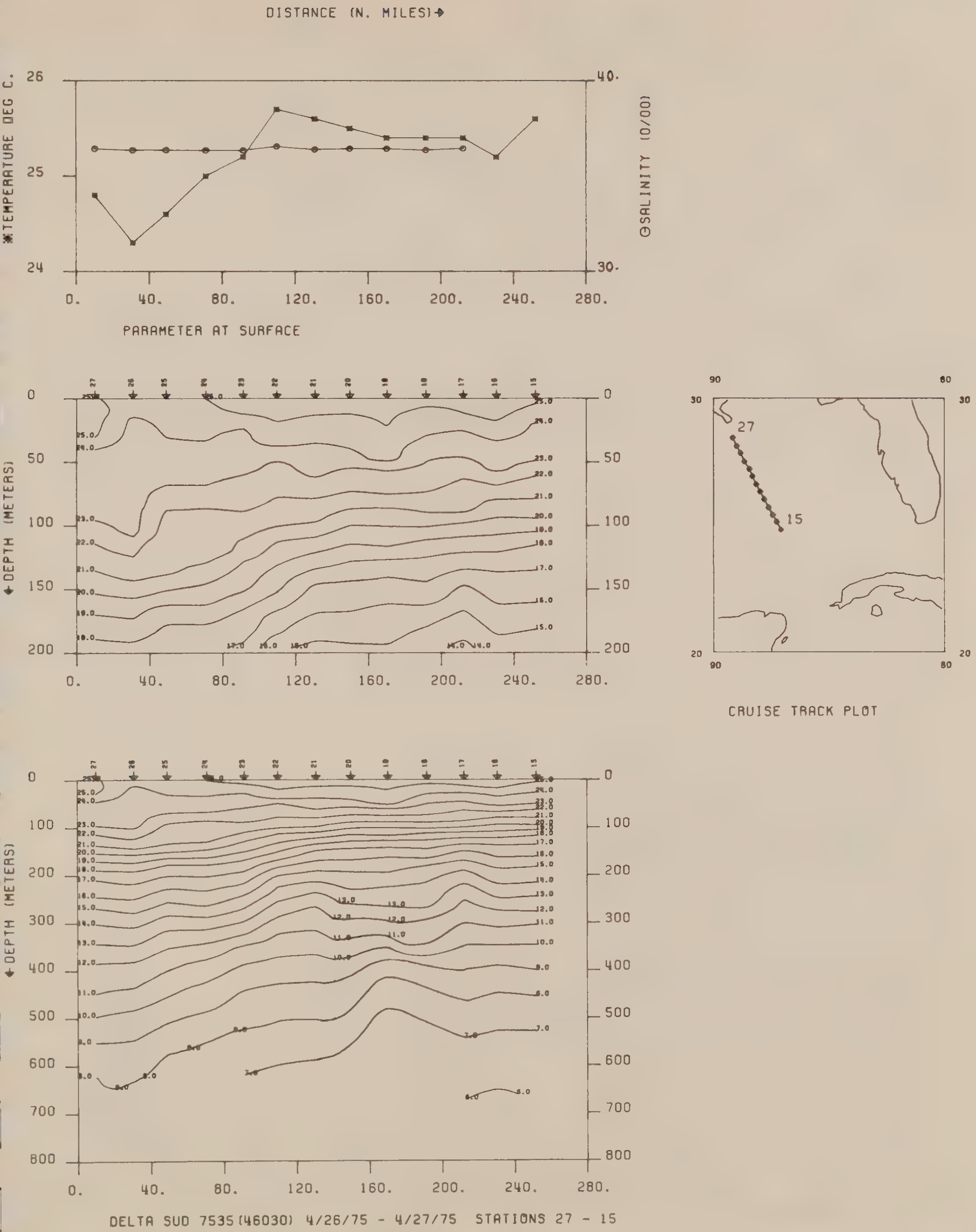
Appendix Figure 5.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Delta Sud*—22-23 March 1975.



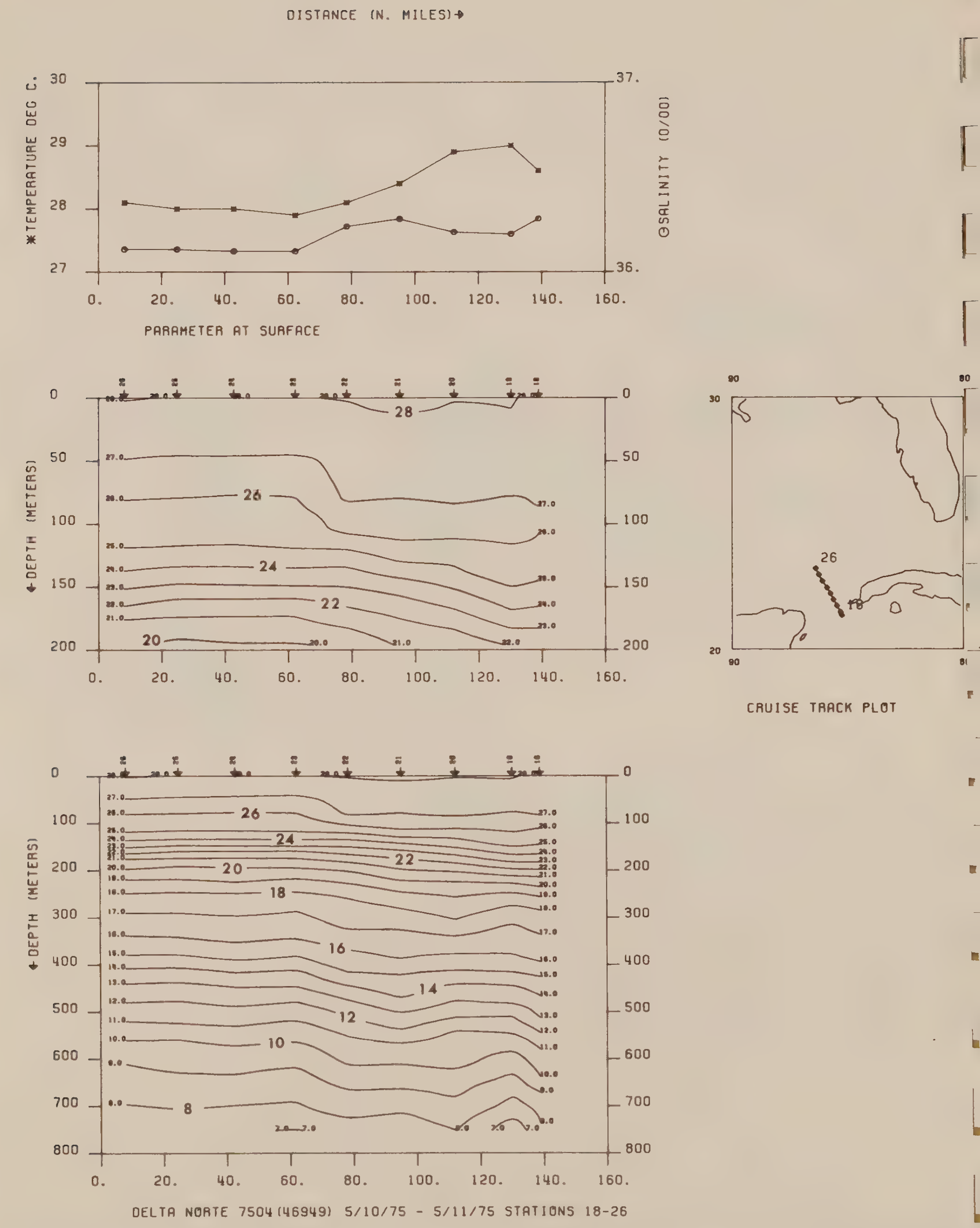
Appendix Figure 6.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Delta Sud*—23-24 March 1975.



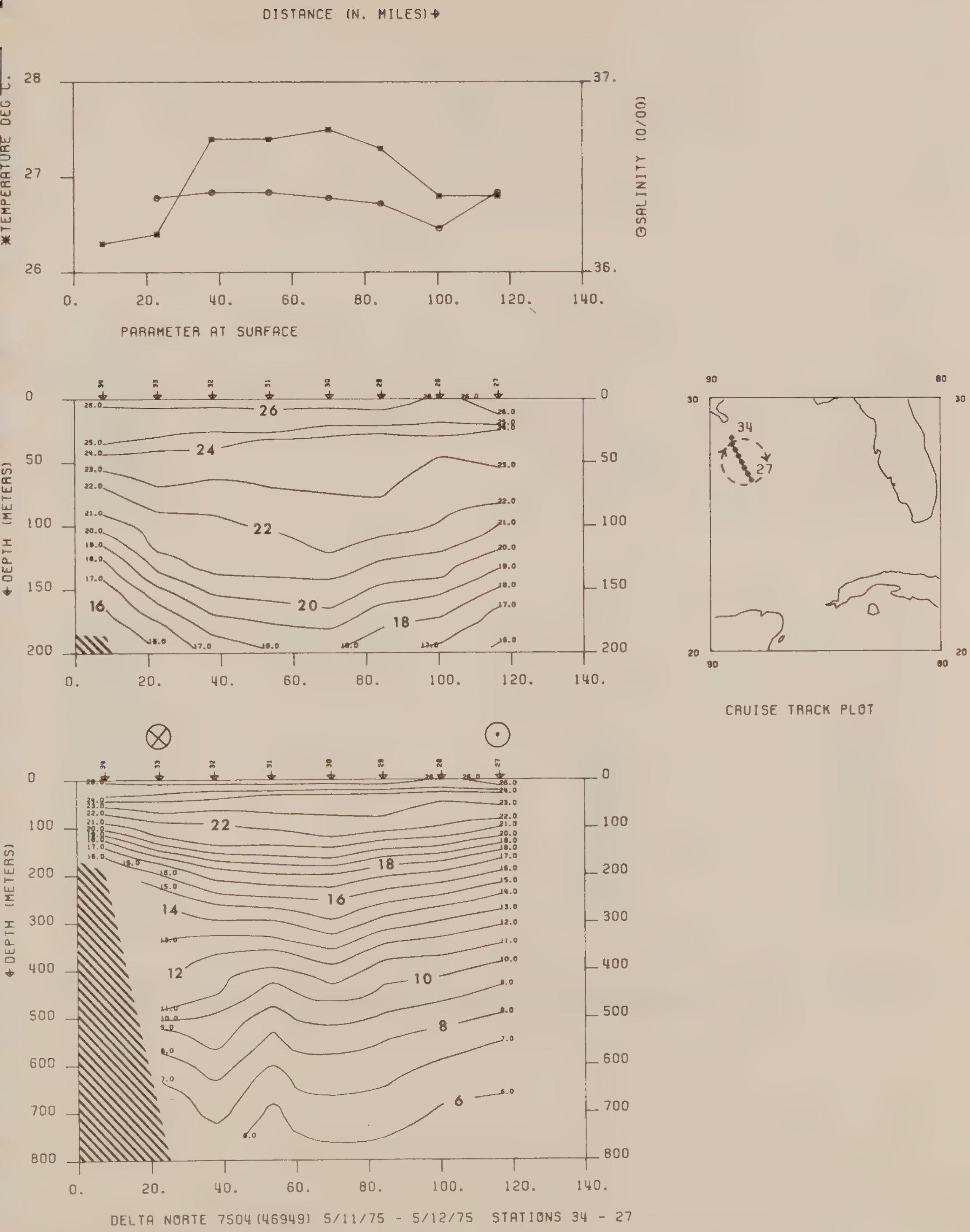
Appendix Figure 7.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Delta Norte*—6 April 1975.



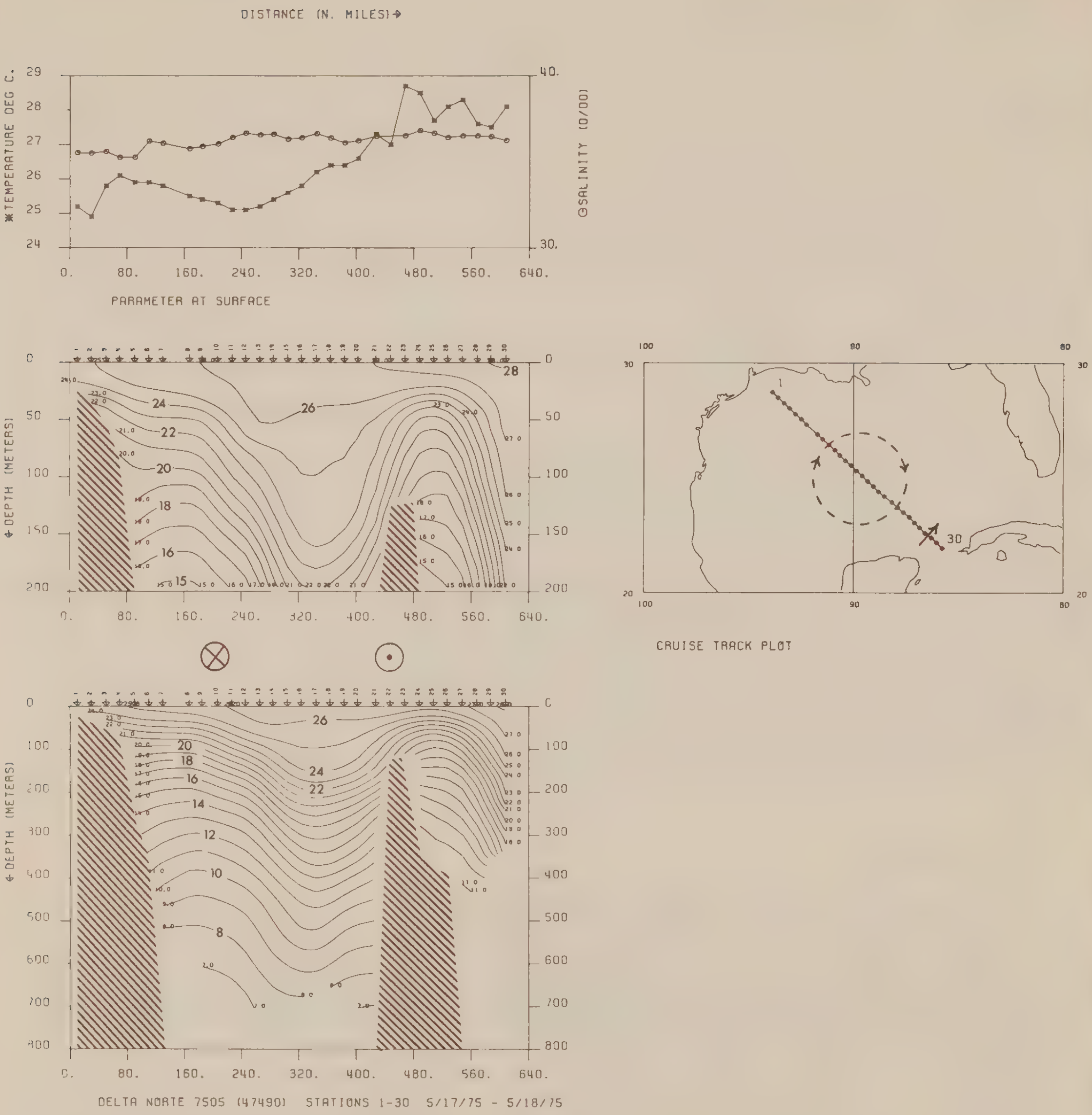
Appendix Figure 8.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Delta Sud*—26-27 April 1975.



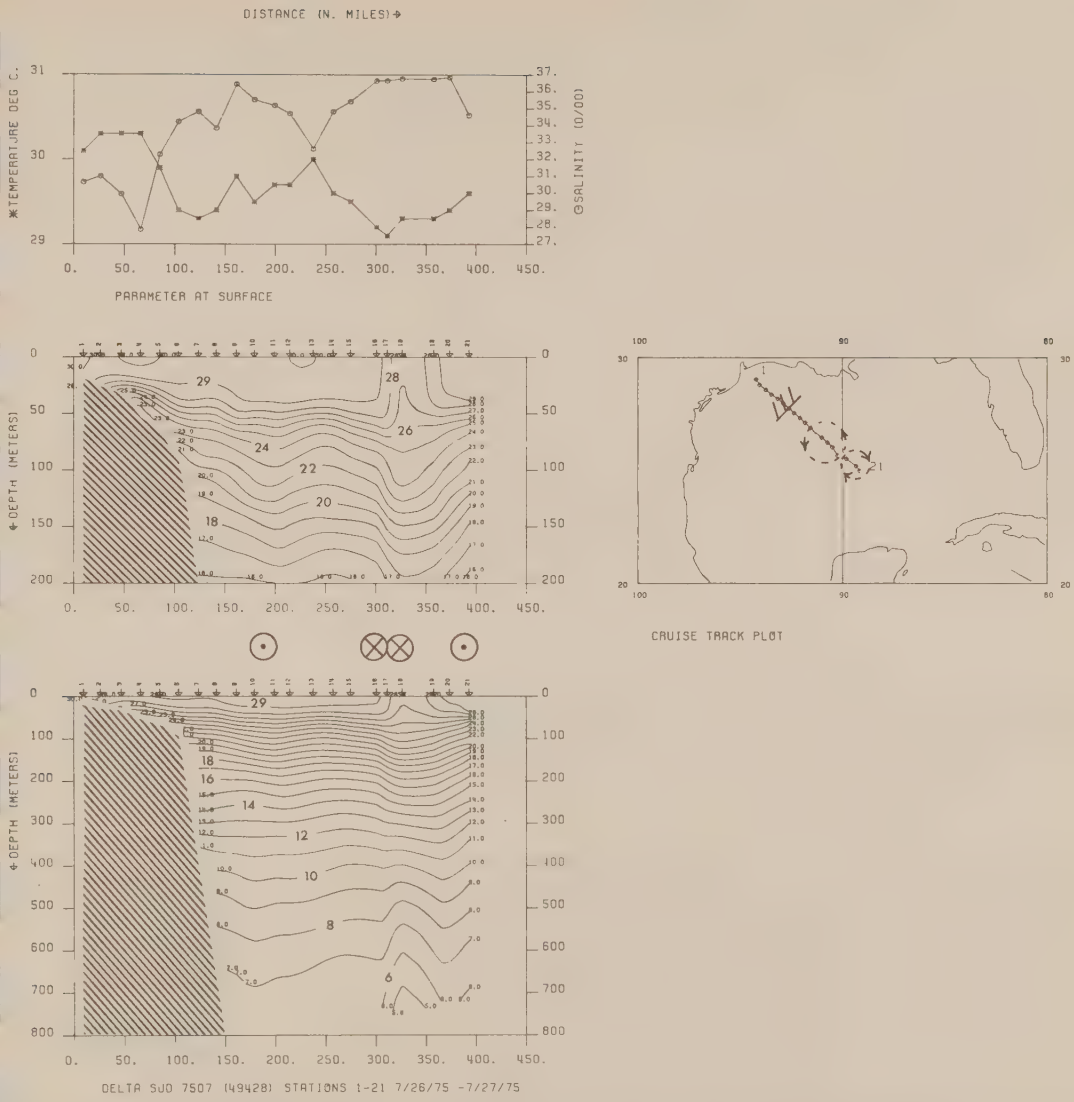
Appendix Figure 9.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution temperature (°C) in the upper 200 and 800 m. *Delta Norte*—10-11 May 1975.



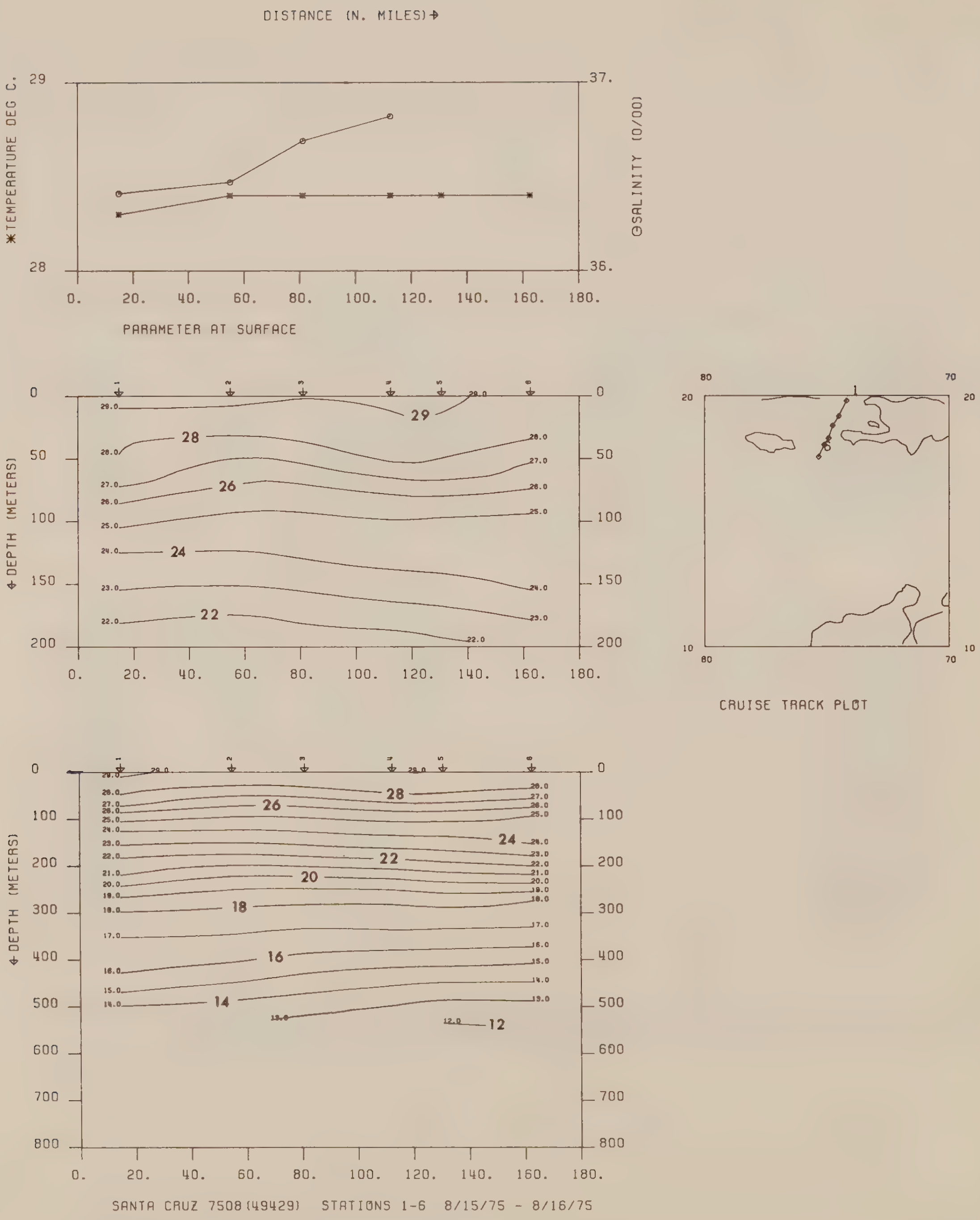
Appendix Figure 10.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Delta Norte*—11-12 May 1975.



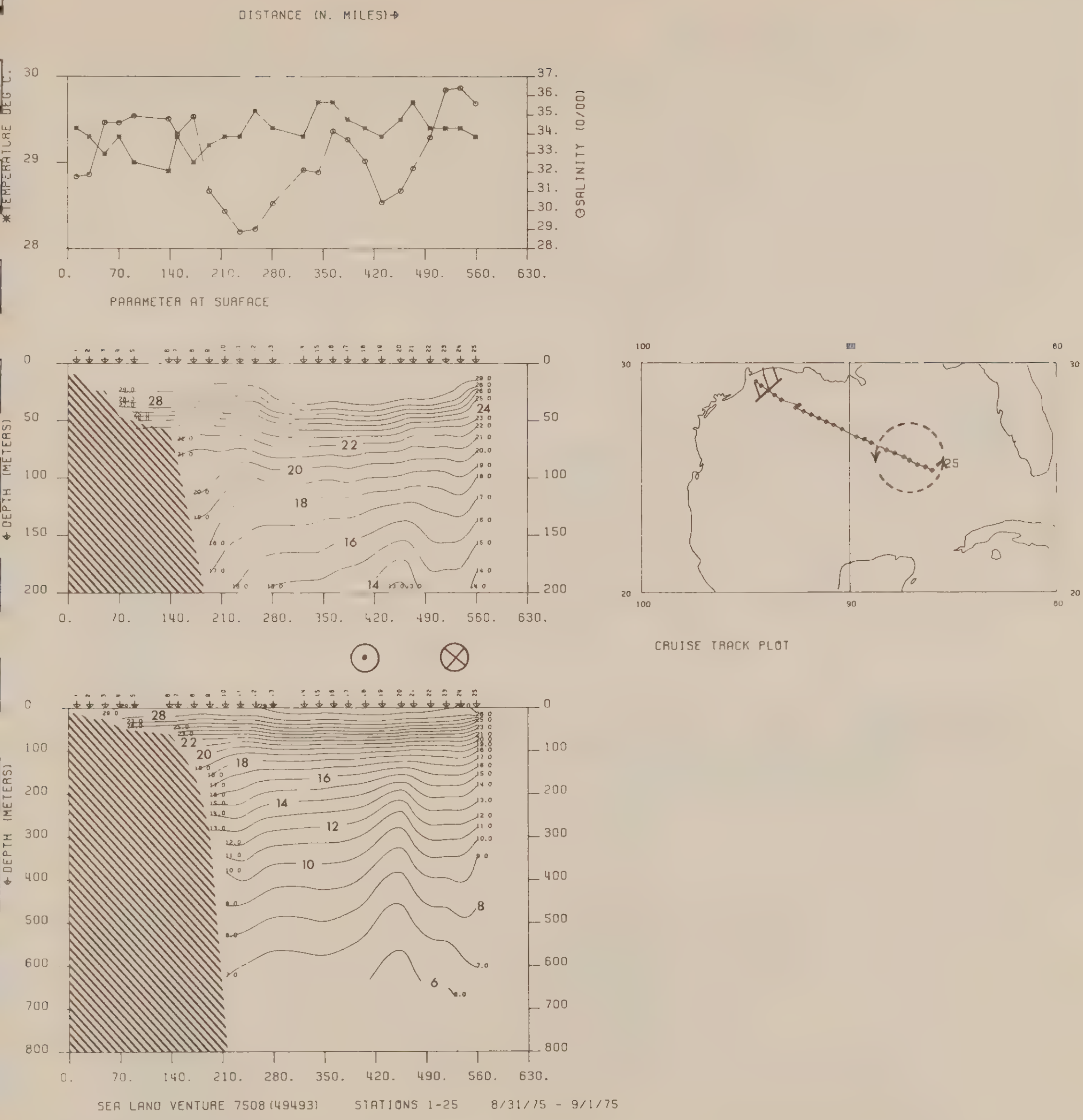
Appendix Figure 11.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Delta Norte*—17-18 May 1975.



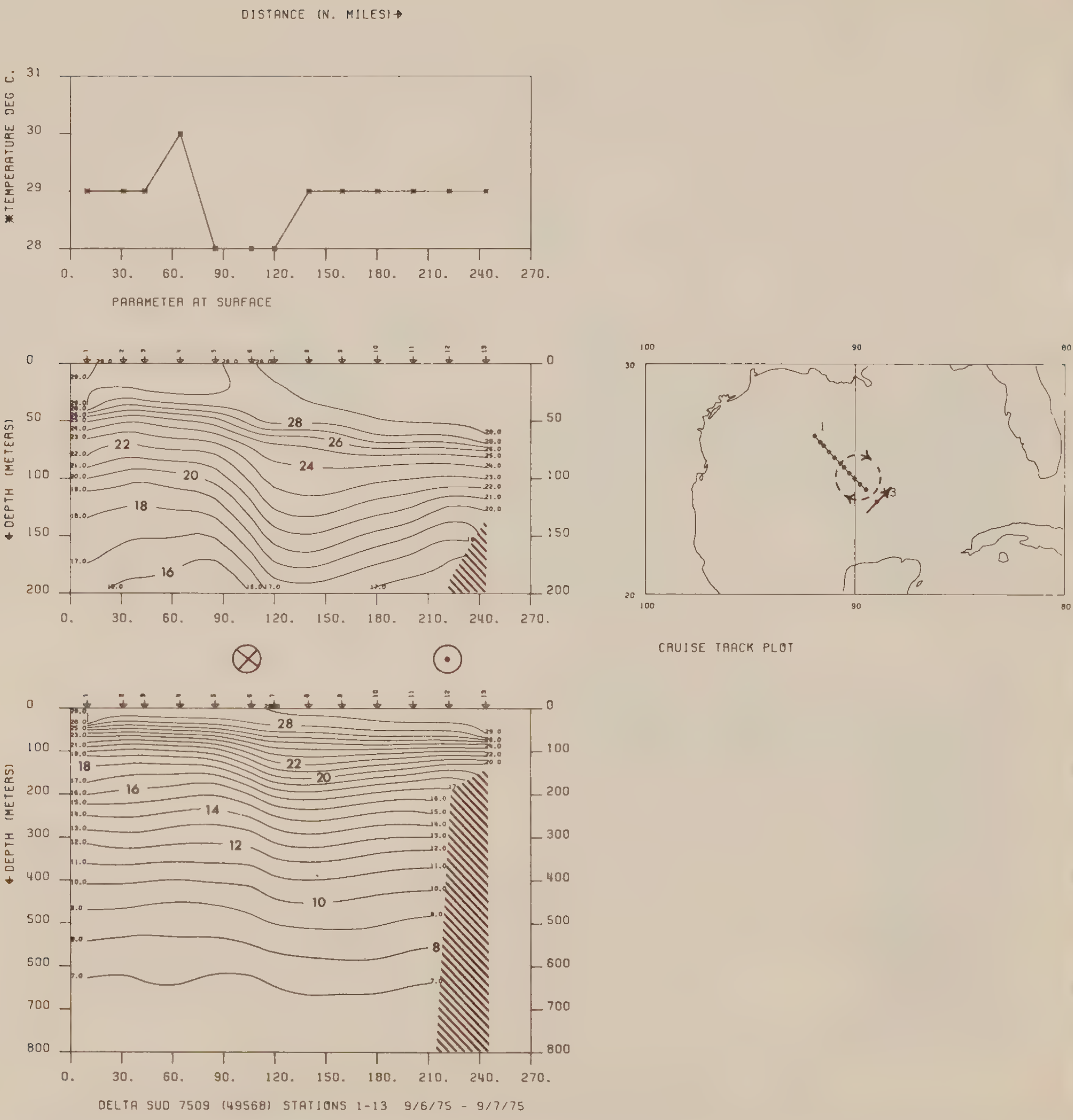
Appendix Figure 12.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Delta Sud*—26-27 July 1975.



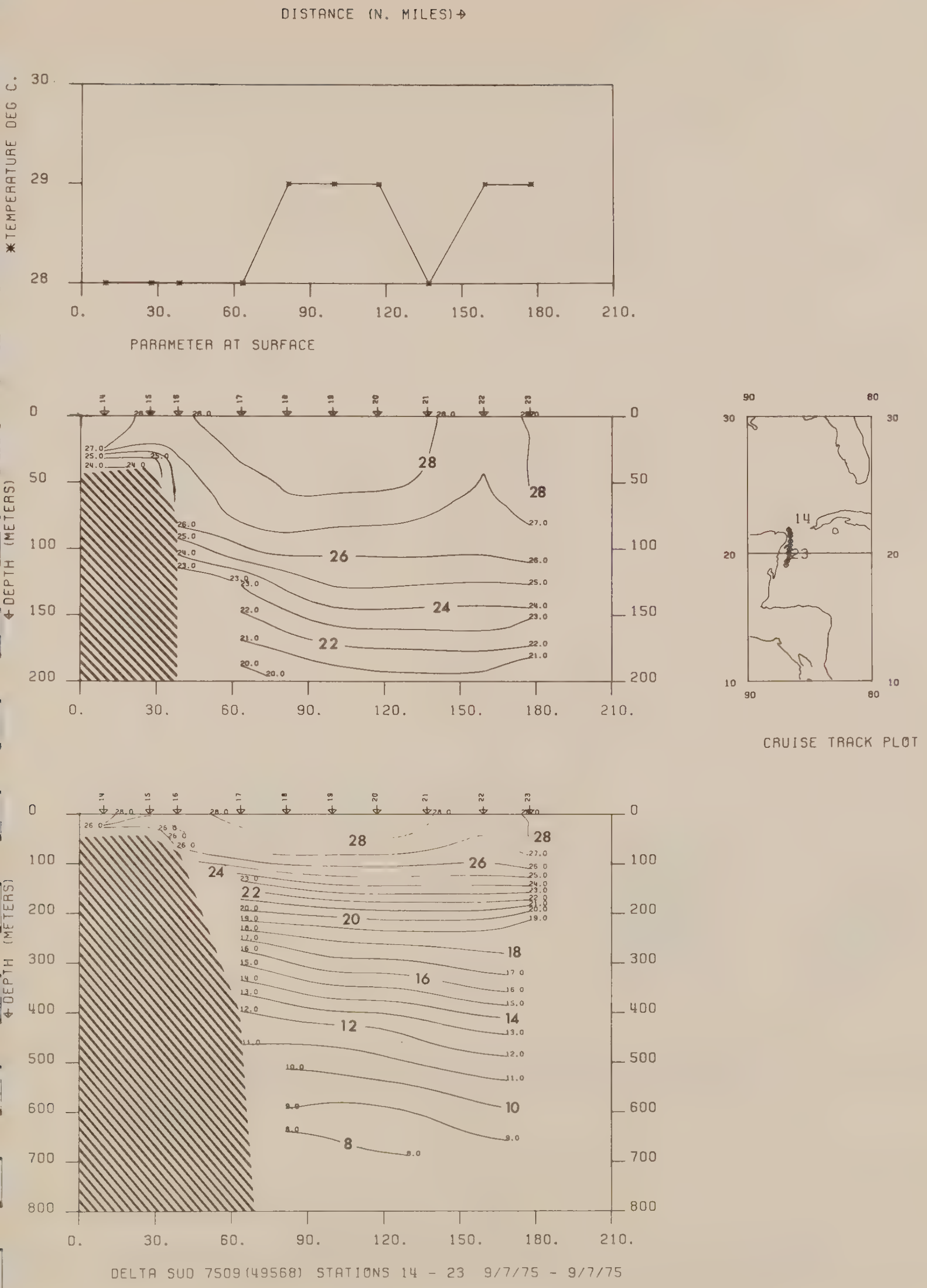
Appendix Figure 13.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distributi of temperature (°C) in the upper 200 and 800 m. *Santa Cruz*—15-16 August 1975.



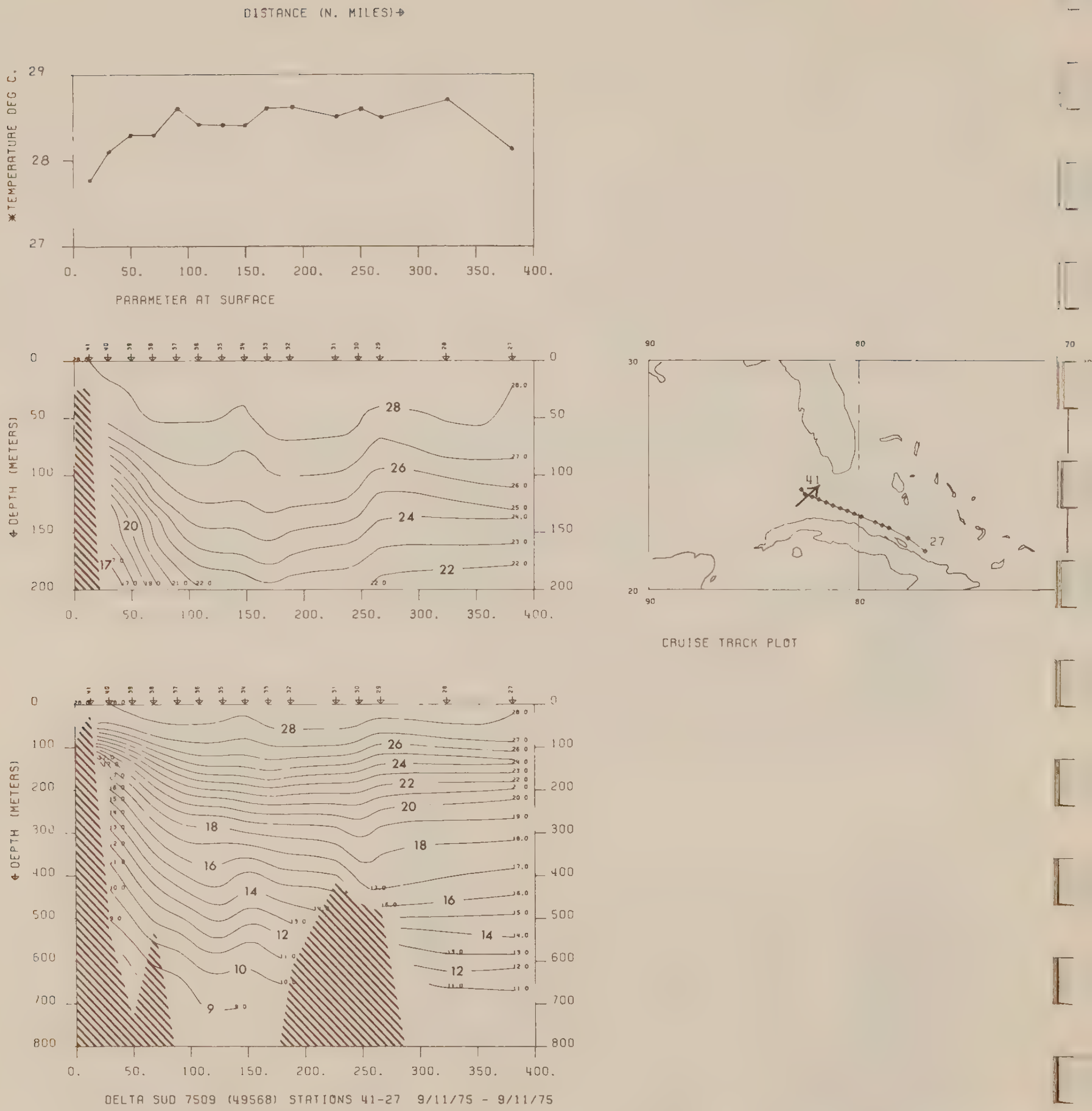
ppendix Figure 14.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Sea Land Venture*—31 August-1 September 1975.



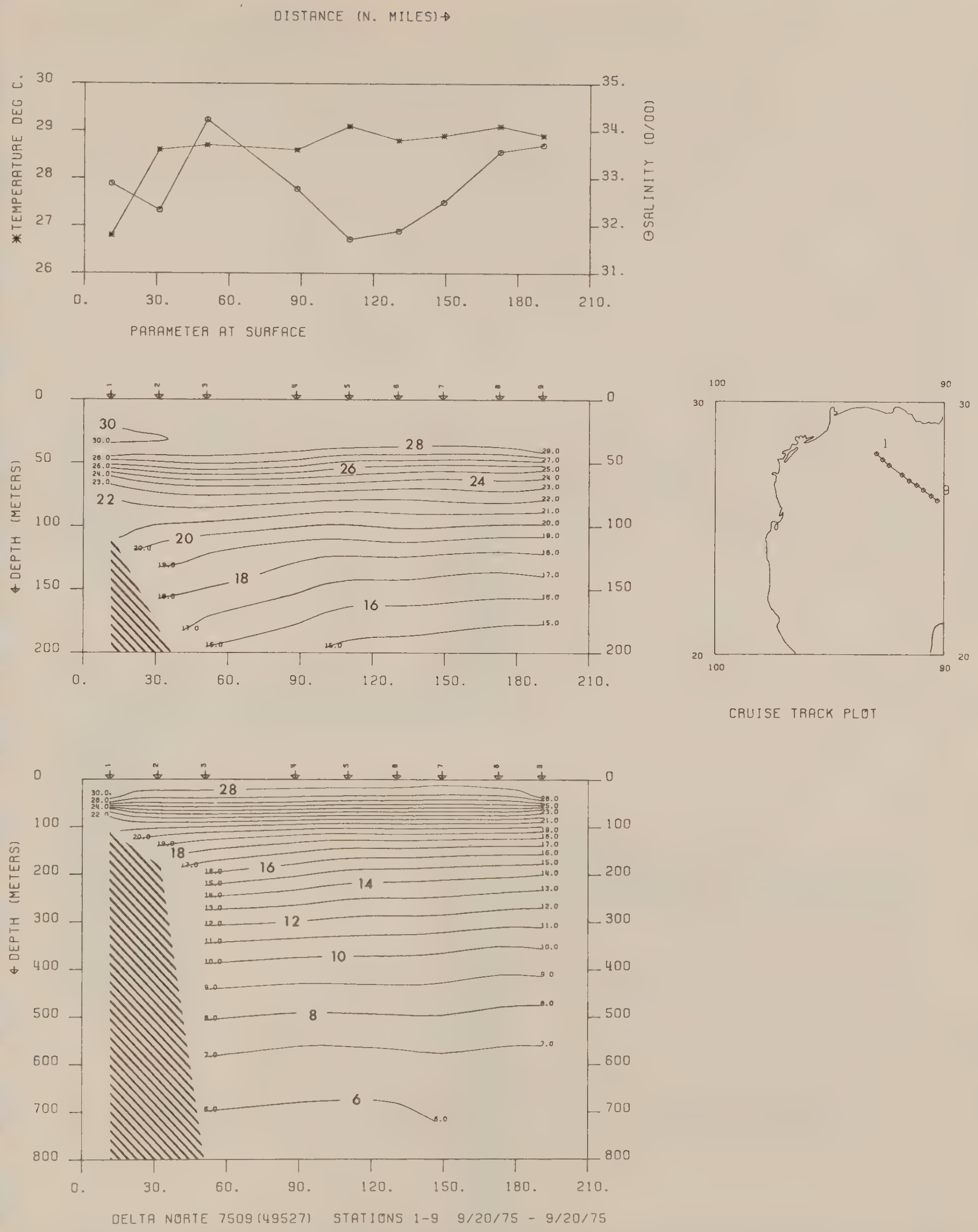
Appendix Figure 15.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distributi of temperature (°C) in the upper 200 and 800 m. *Delta Sud*—6-7 September 1975.



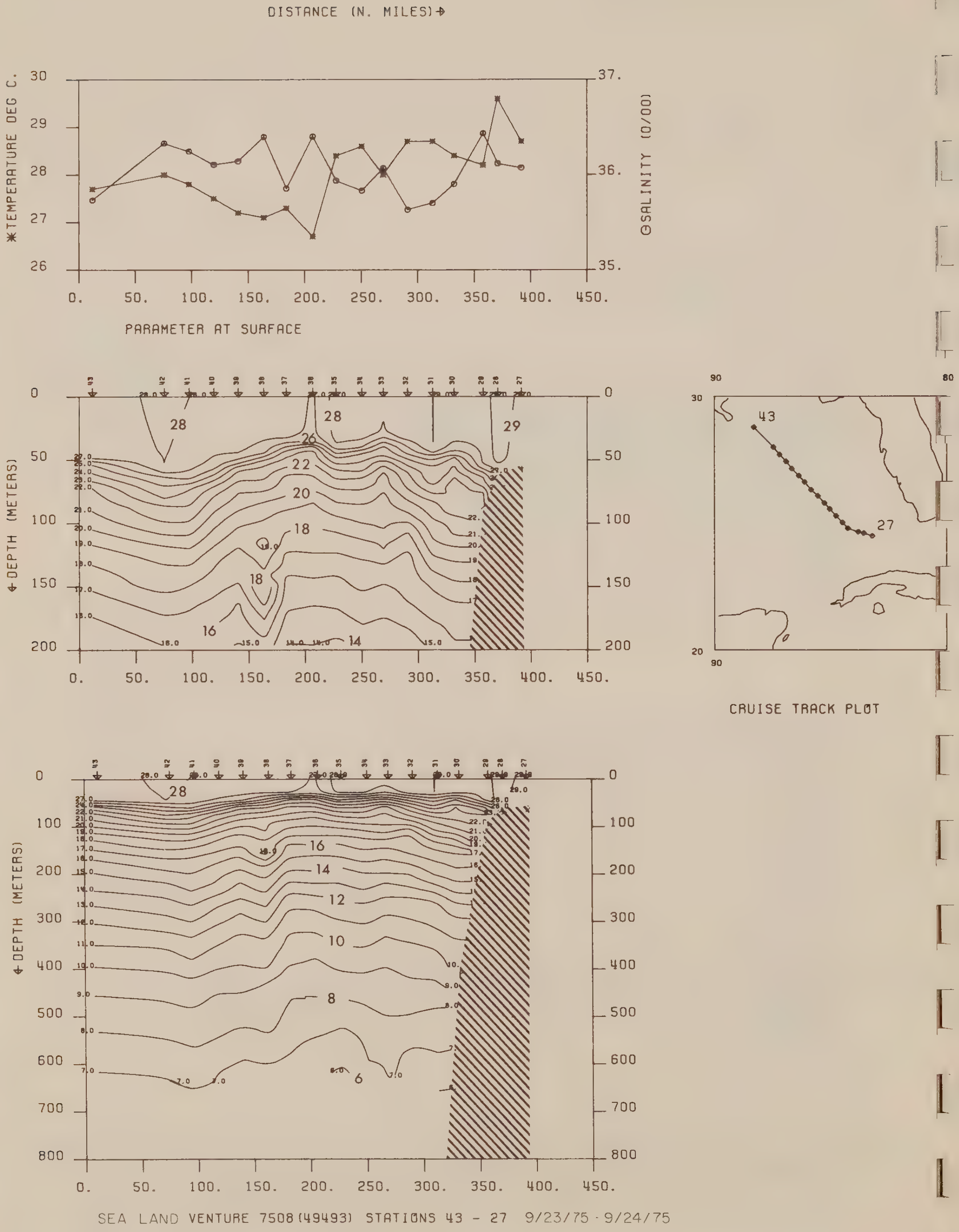
Appendix Figure 16.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Delta Sud*—7 September 1975.



Appendix Figure 17.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Delta Sud*—11 September 1975.



Appendix Figure 18.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Delta Norte*—20 September 1975.



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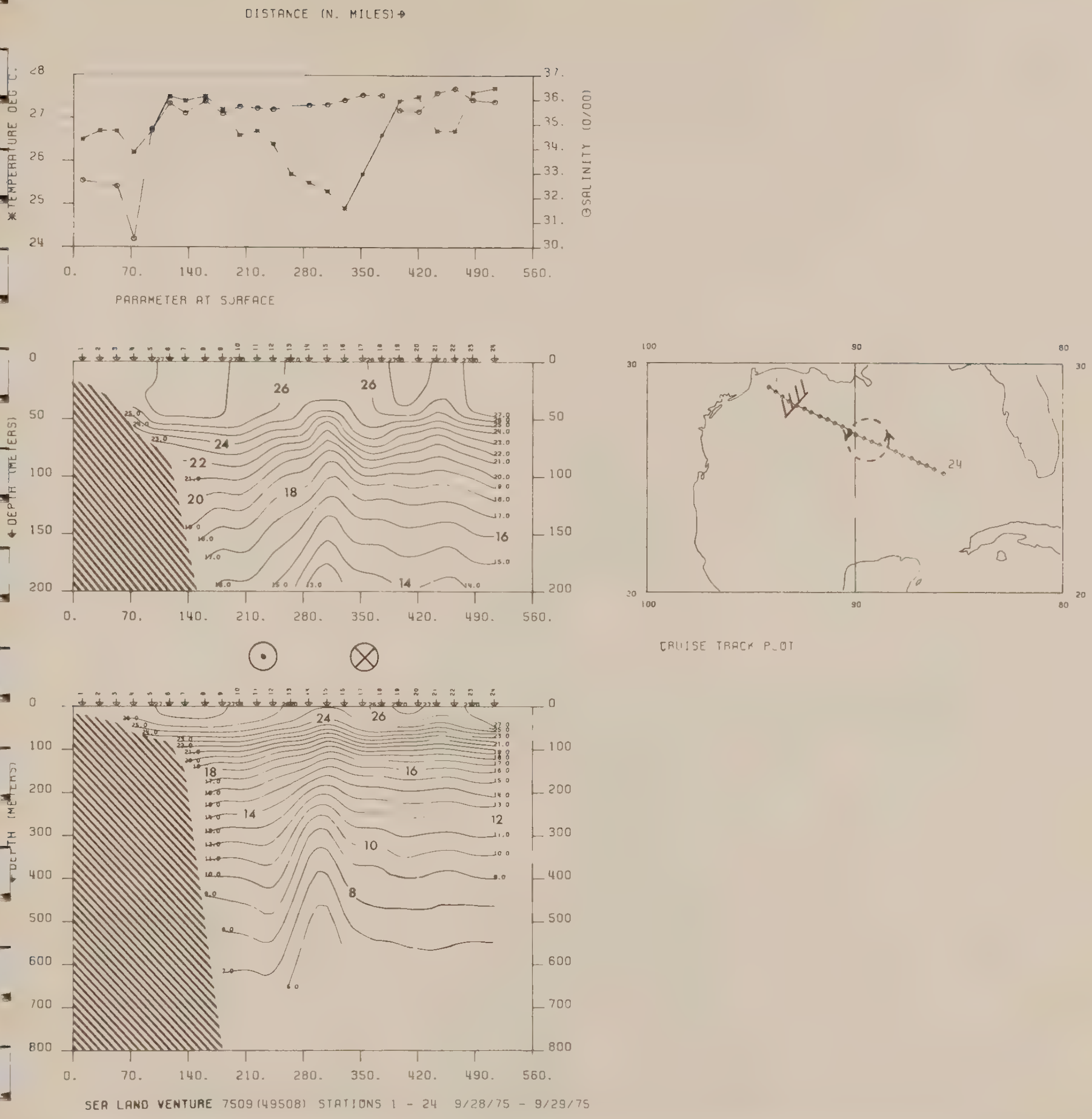
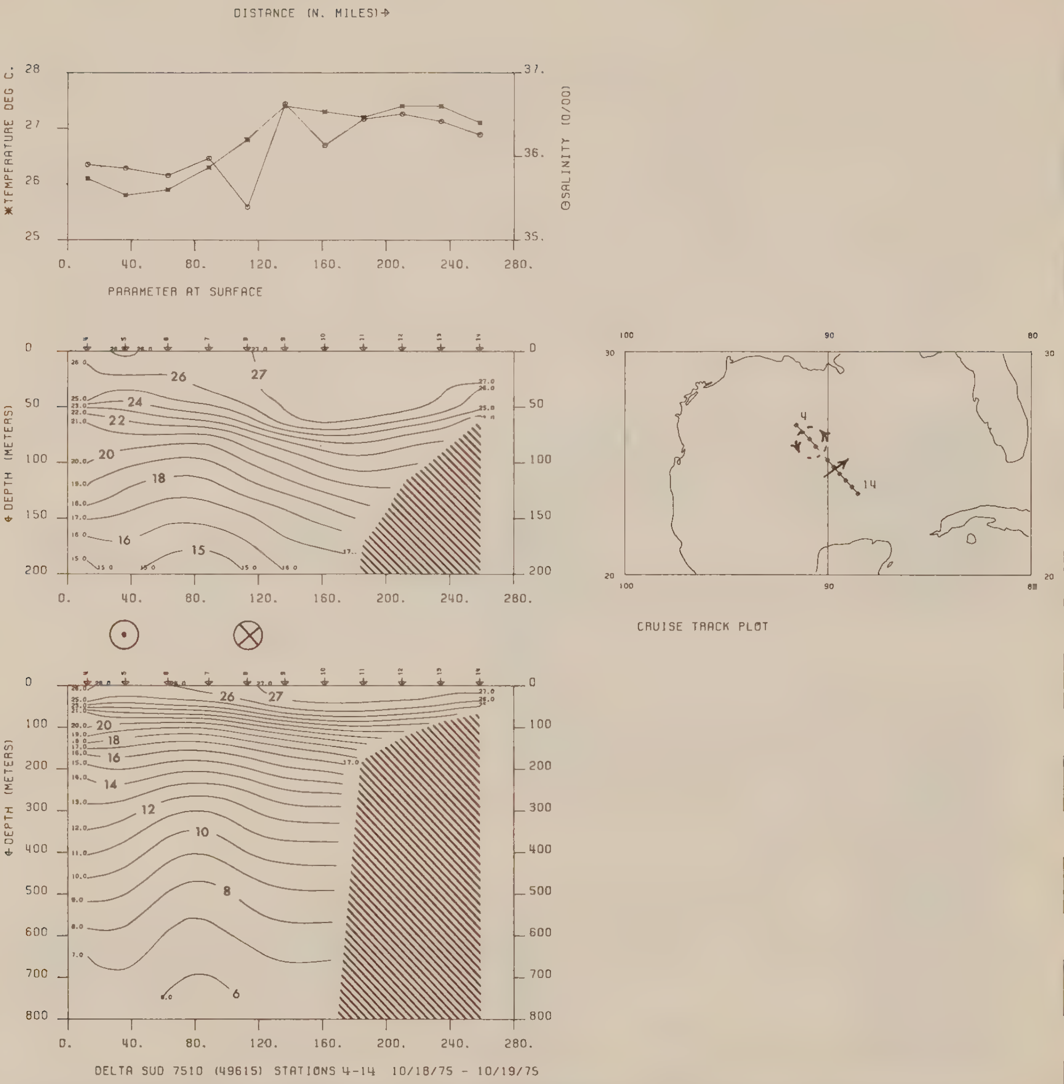
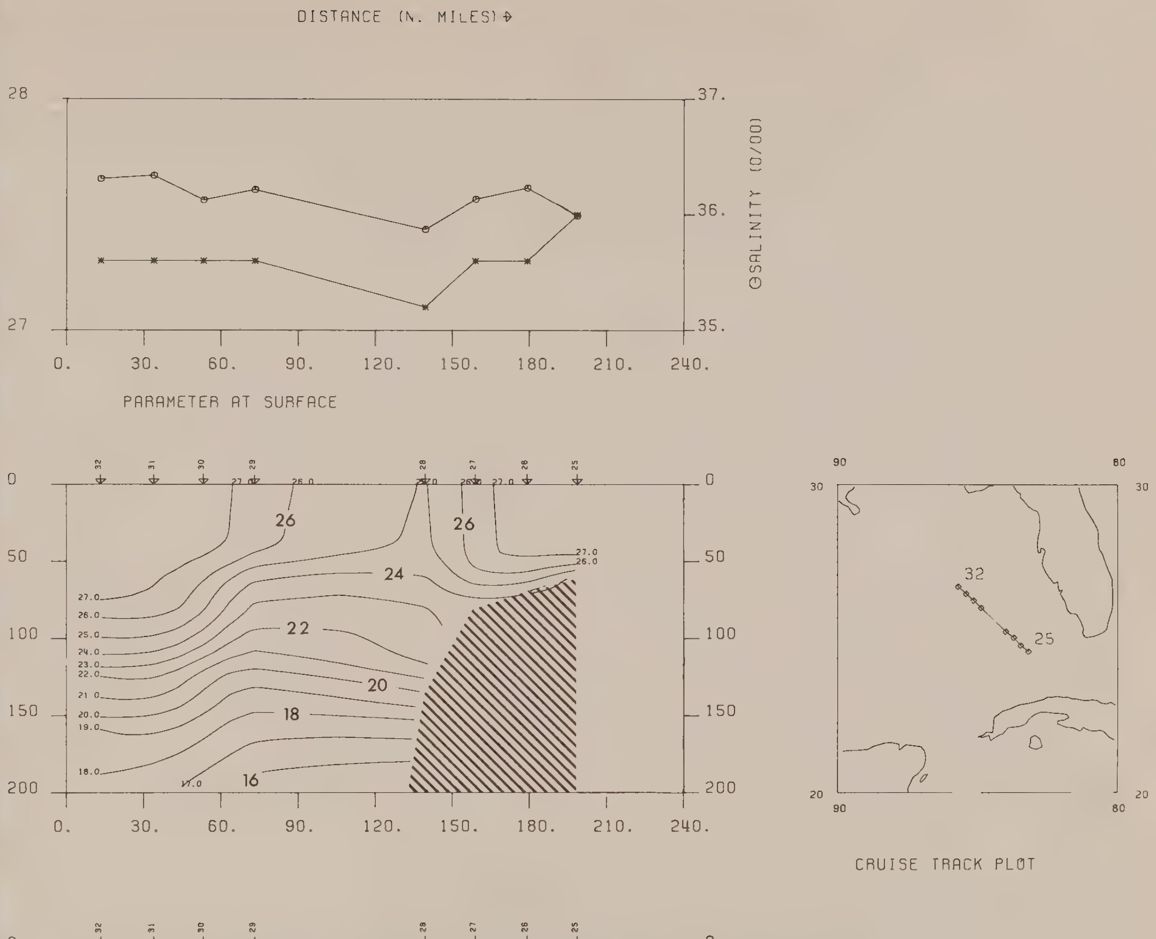
Appendix Figure 19.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distributi temperature (°C) in the upper 200 and 800 m. *Sea Land Venture*—23-24 September 1975.



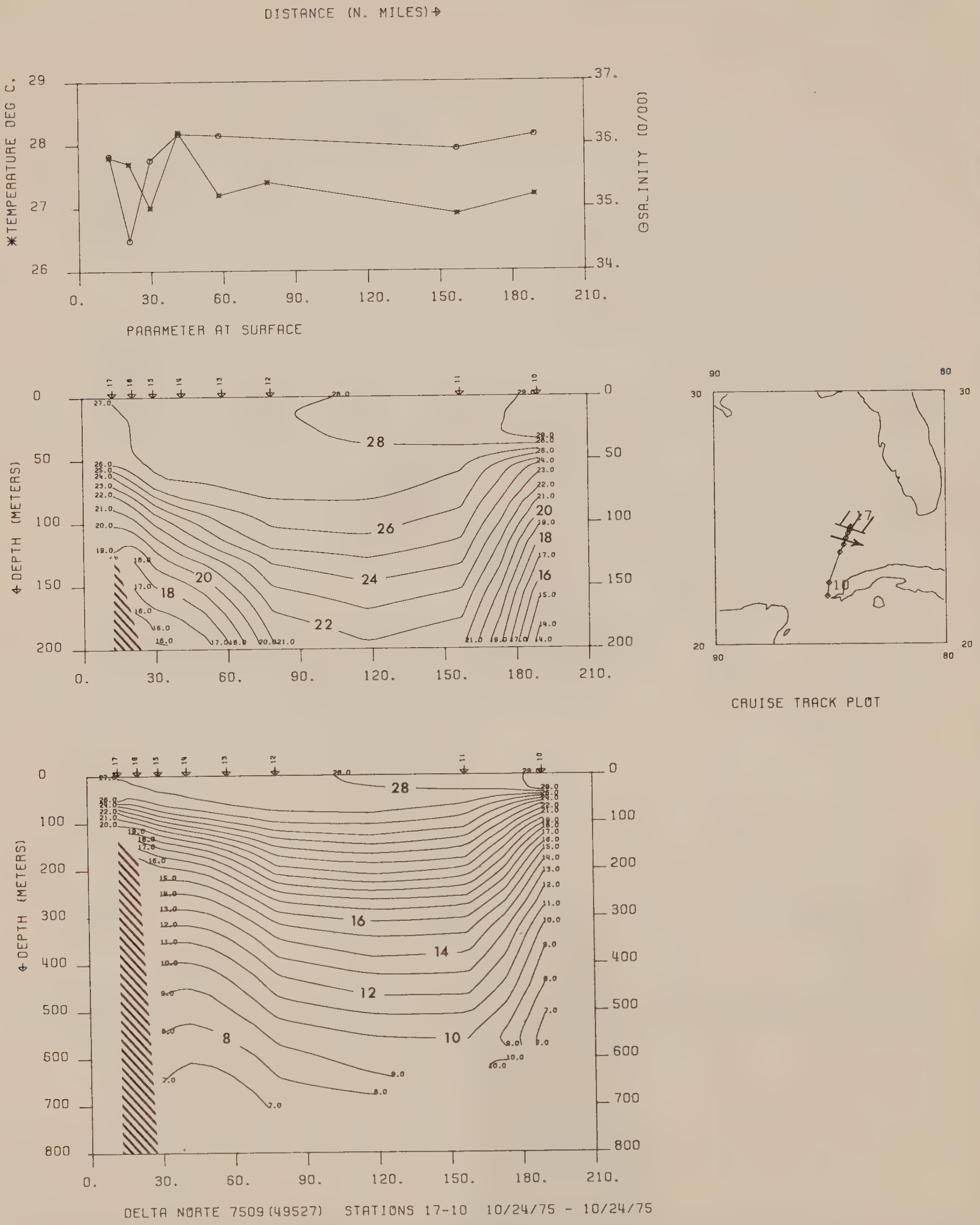
ppendix Figure 20.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Sea Land Venture*—28-29 September 1975.



Appendix Figure 21.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Delta Sud*—18-19 October 1975.



pendix Figure 22.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Sea Land Venture*—20 October 1975.



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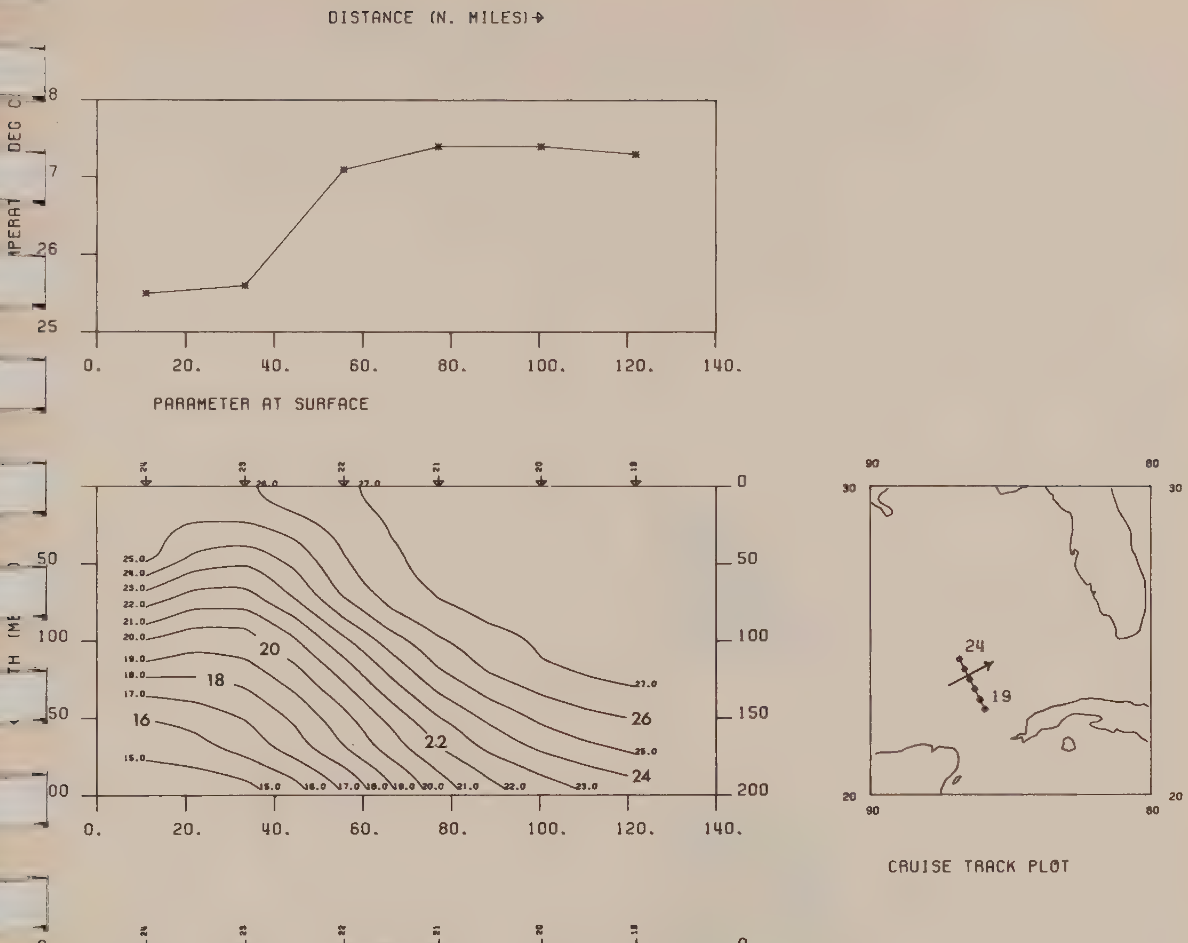
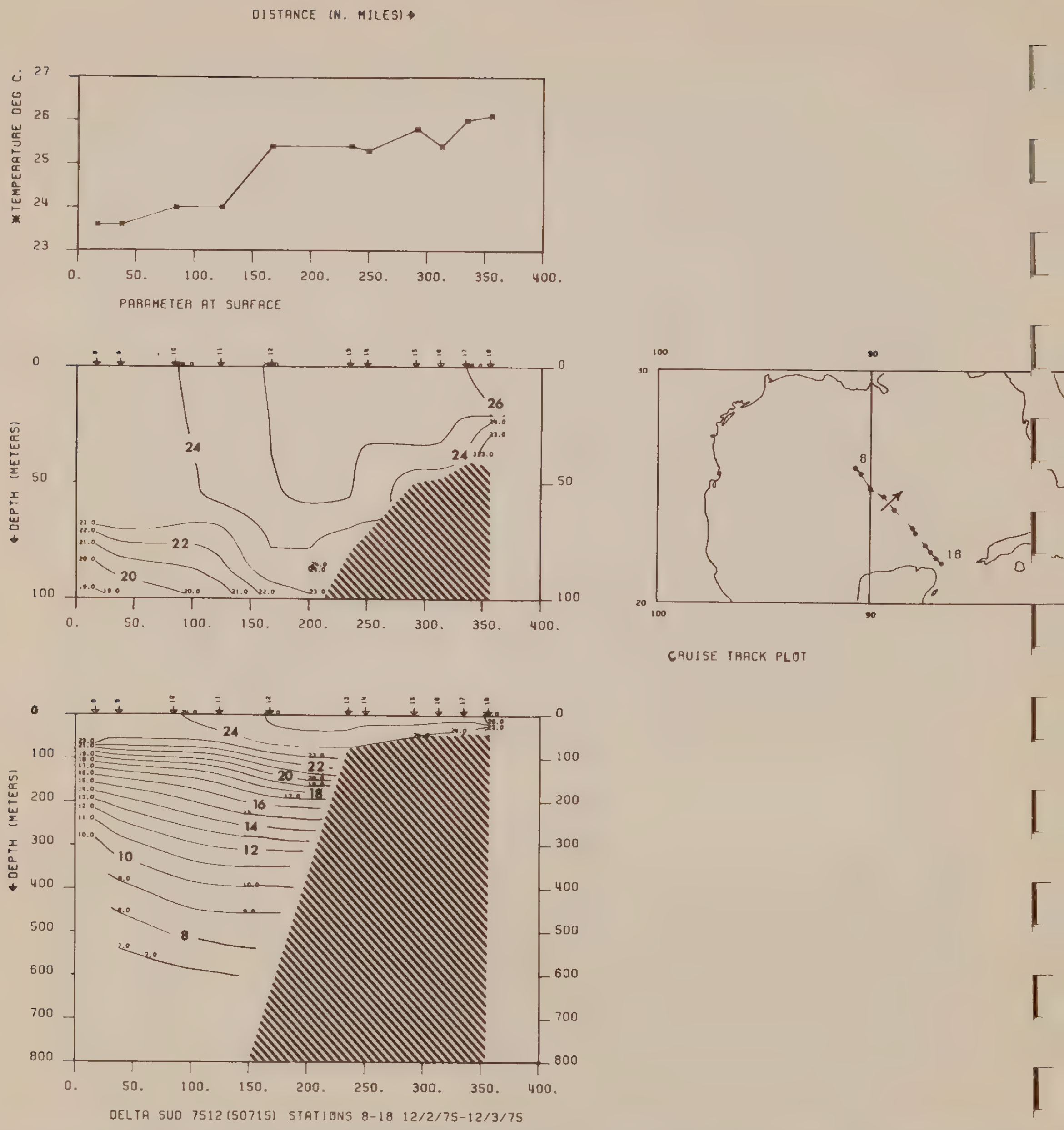
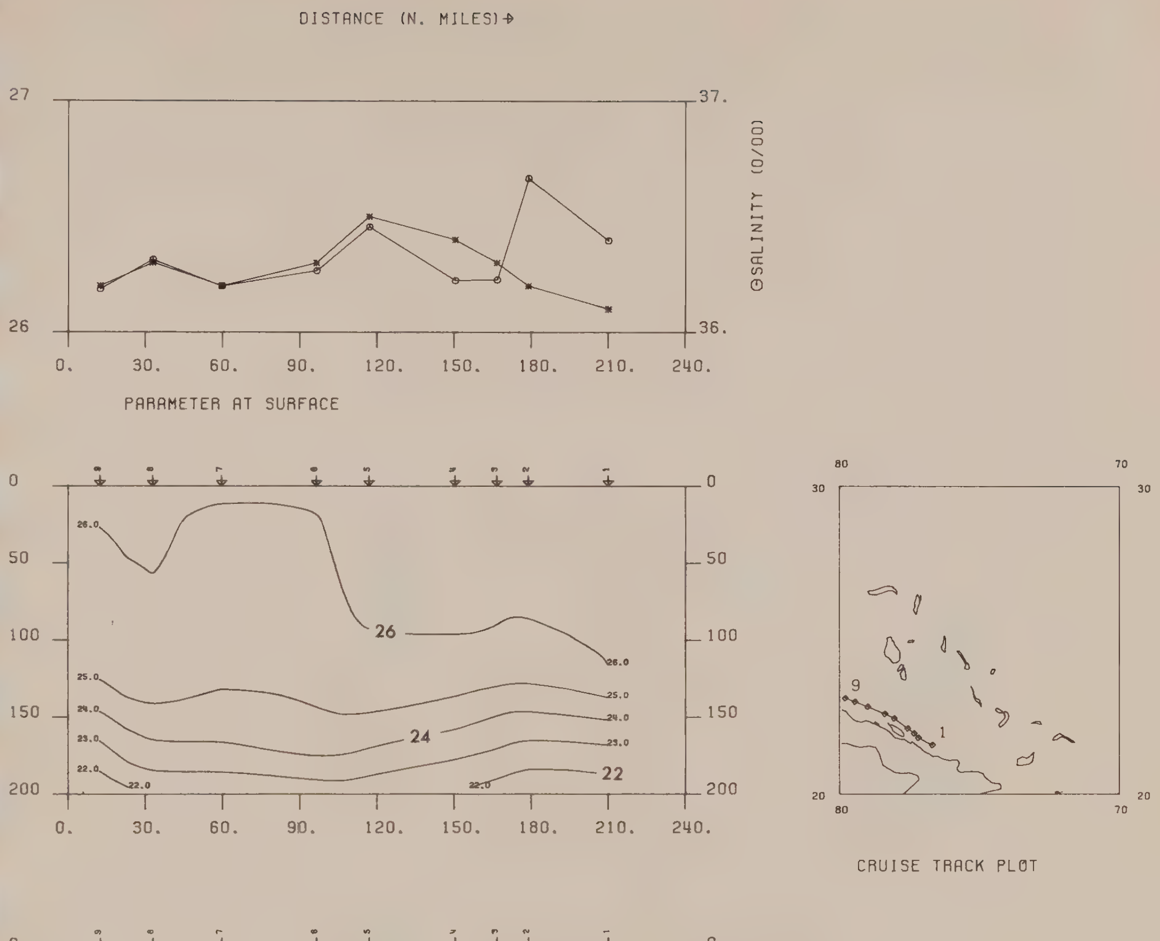


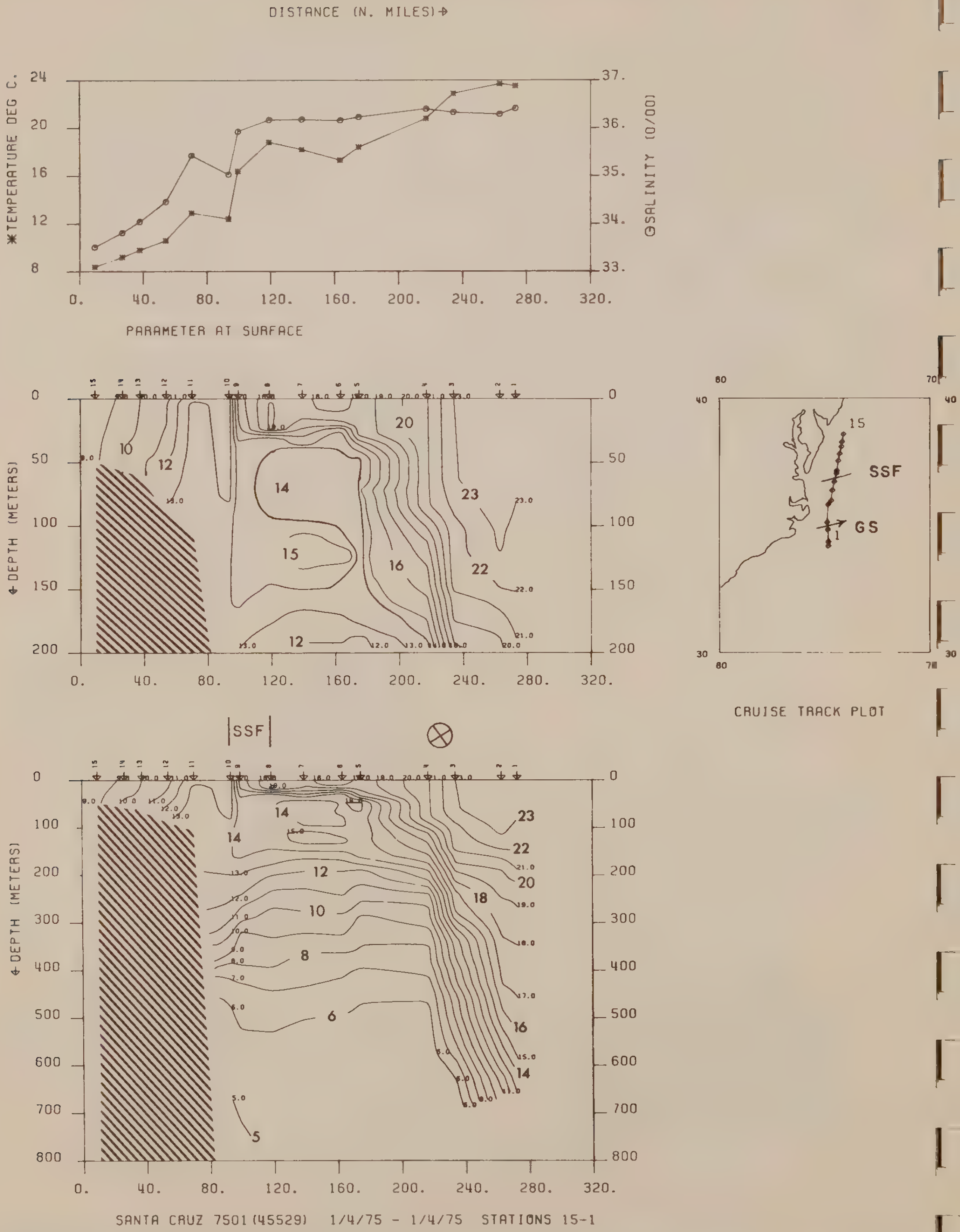
dix Figure 24.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Delta Sud*—23-24 November 1975.



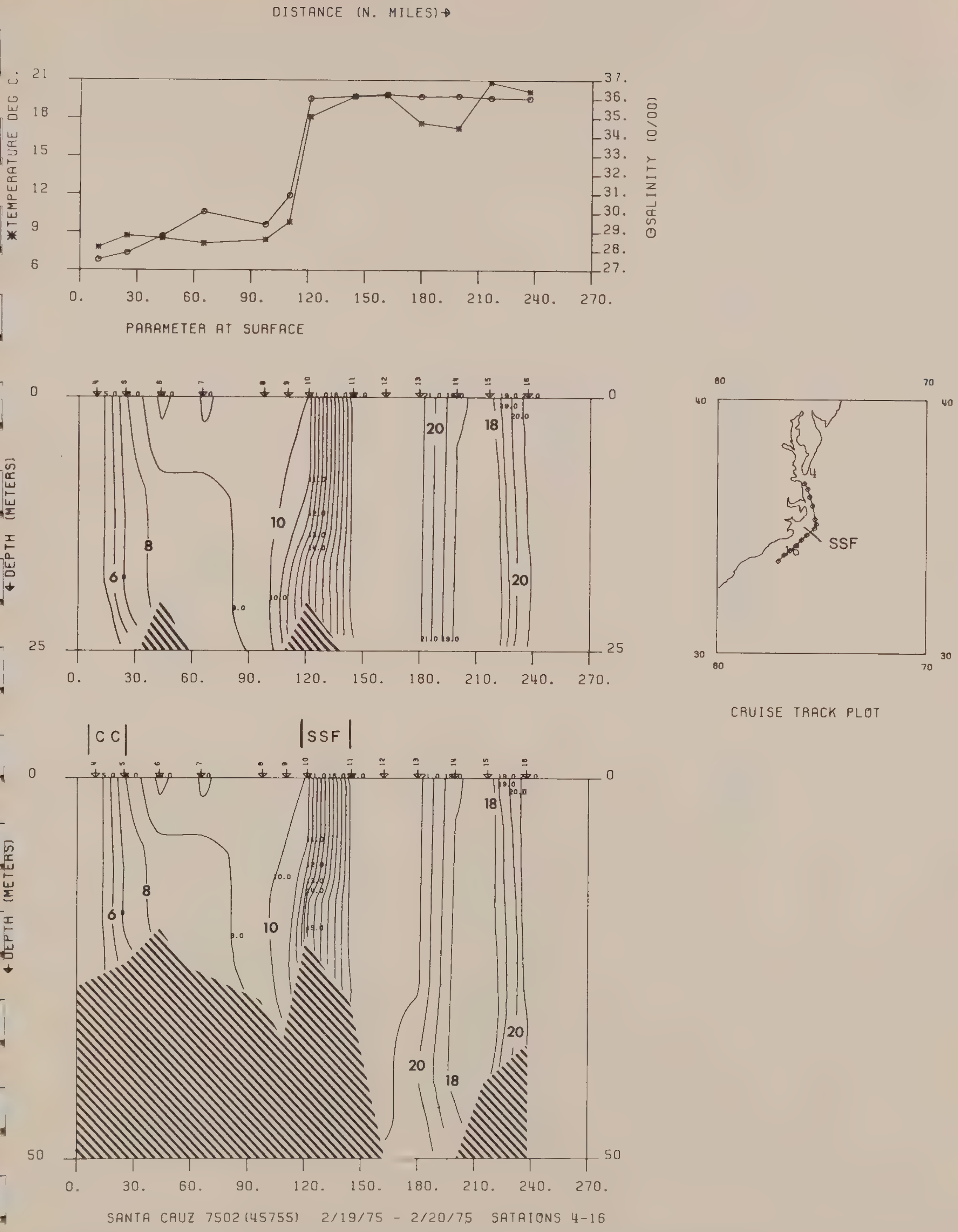
Appendix Figure 25.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of perature (°C) in the upper 200 and 800 m. *Delta Sud*—2-3 December 1975.



pendix Figure 26.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Delta Norte*—5-6 December 1975.



Appendix Figure 27.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Santa Cruz*—4 January 1975.



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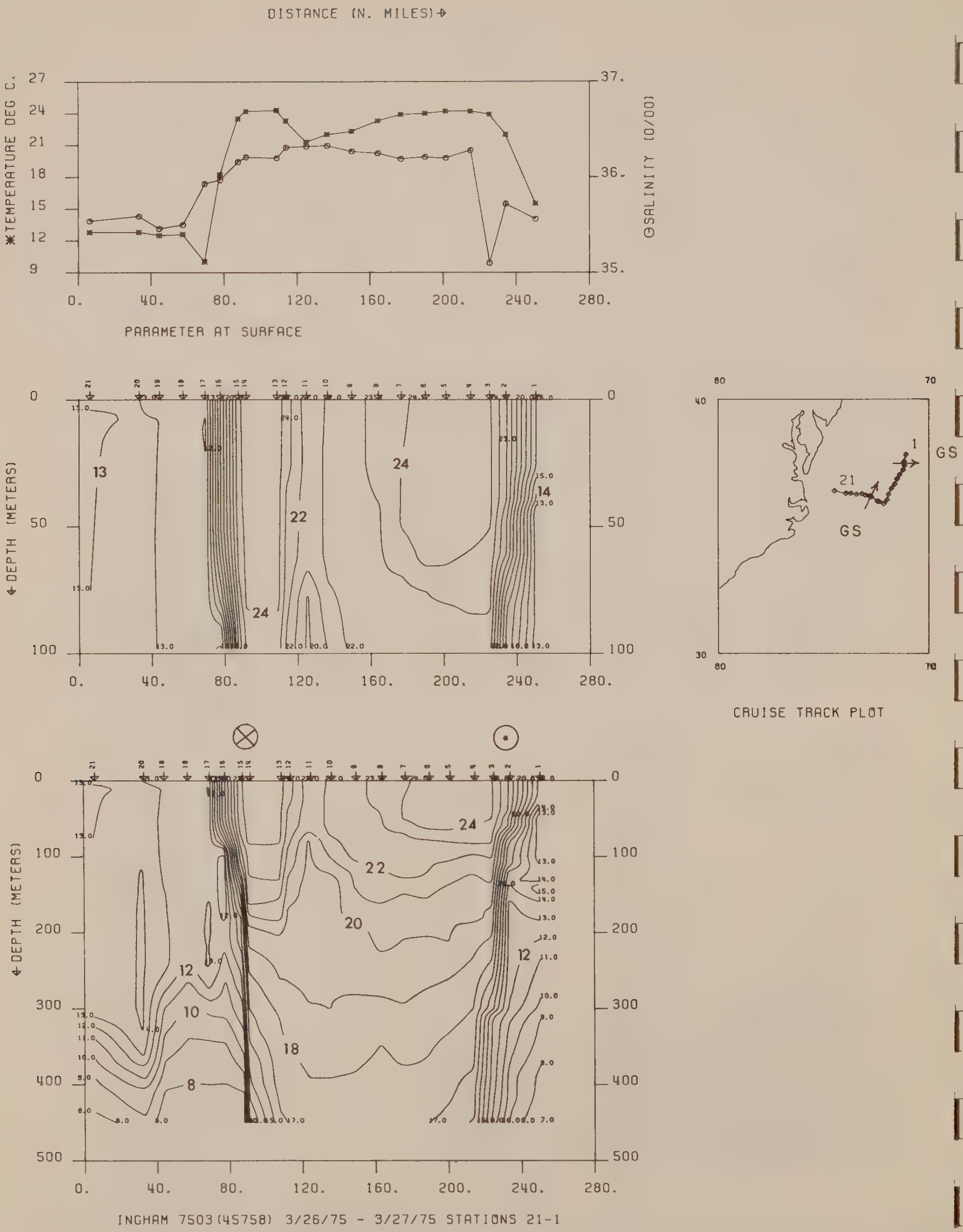
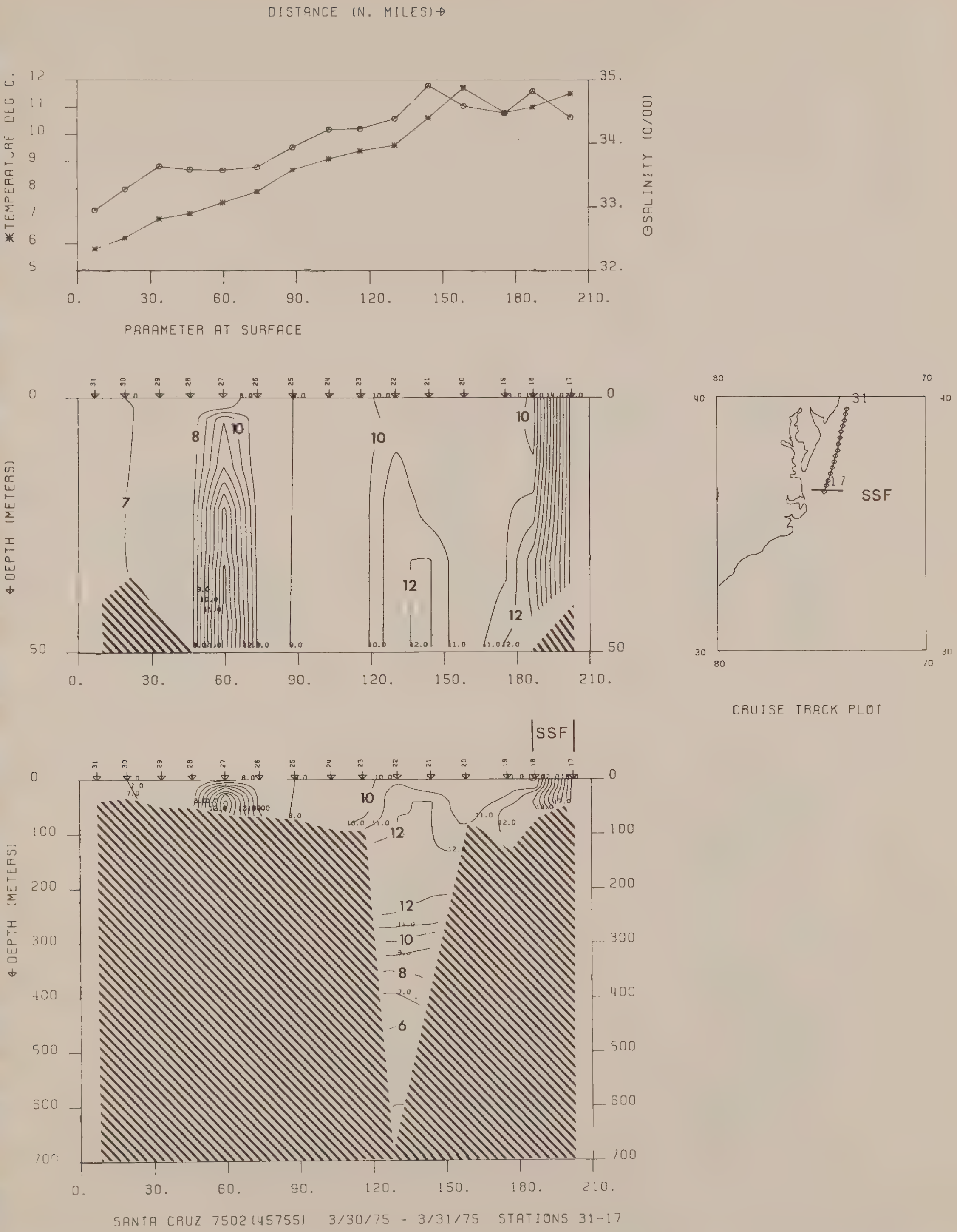
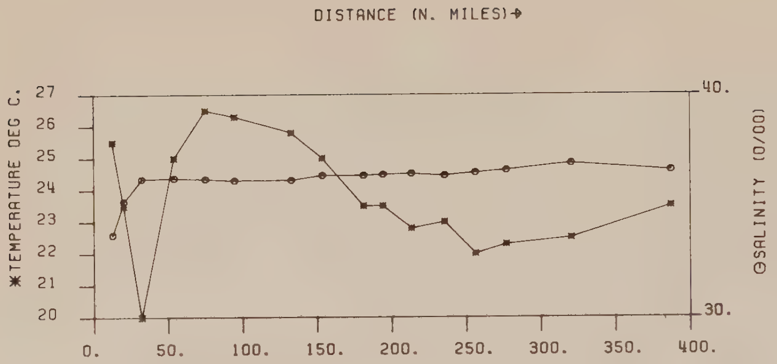


Appendix Figure 29.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 100 and 500 m. *Ingham*—26-27 March 1975.



Appendix Figure 30.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 50 and 700 m. *Santa Cruz*—30-31 March 1975.



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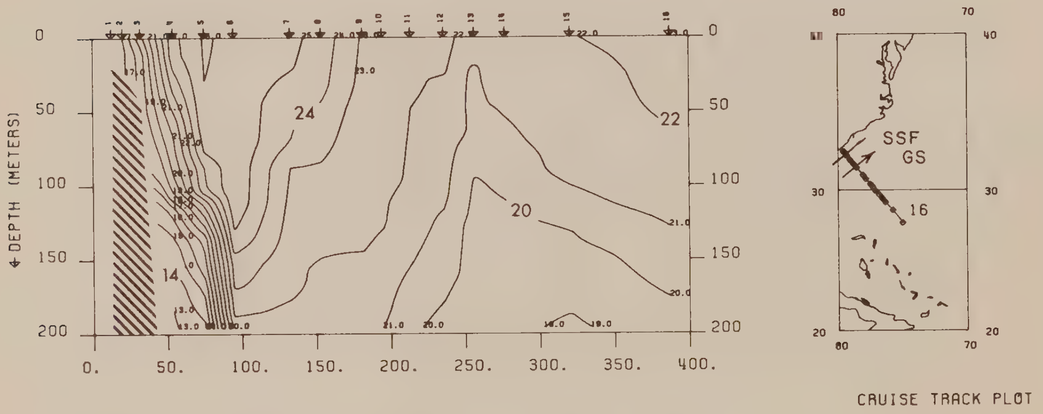

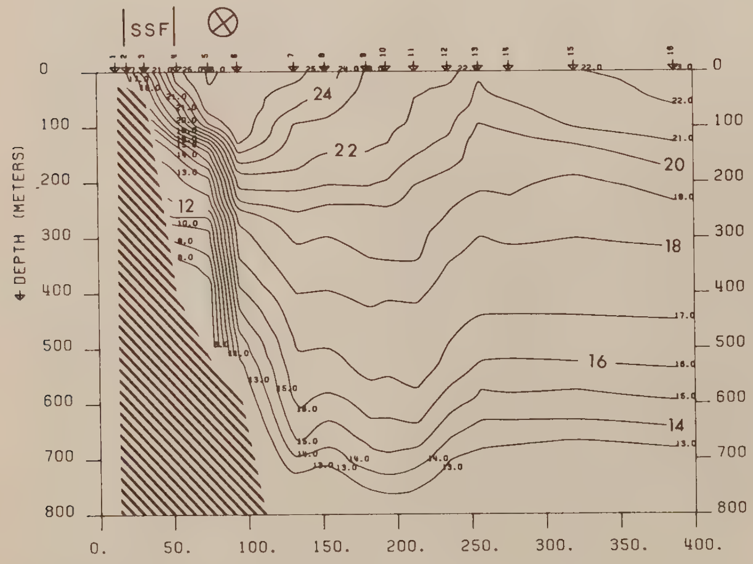

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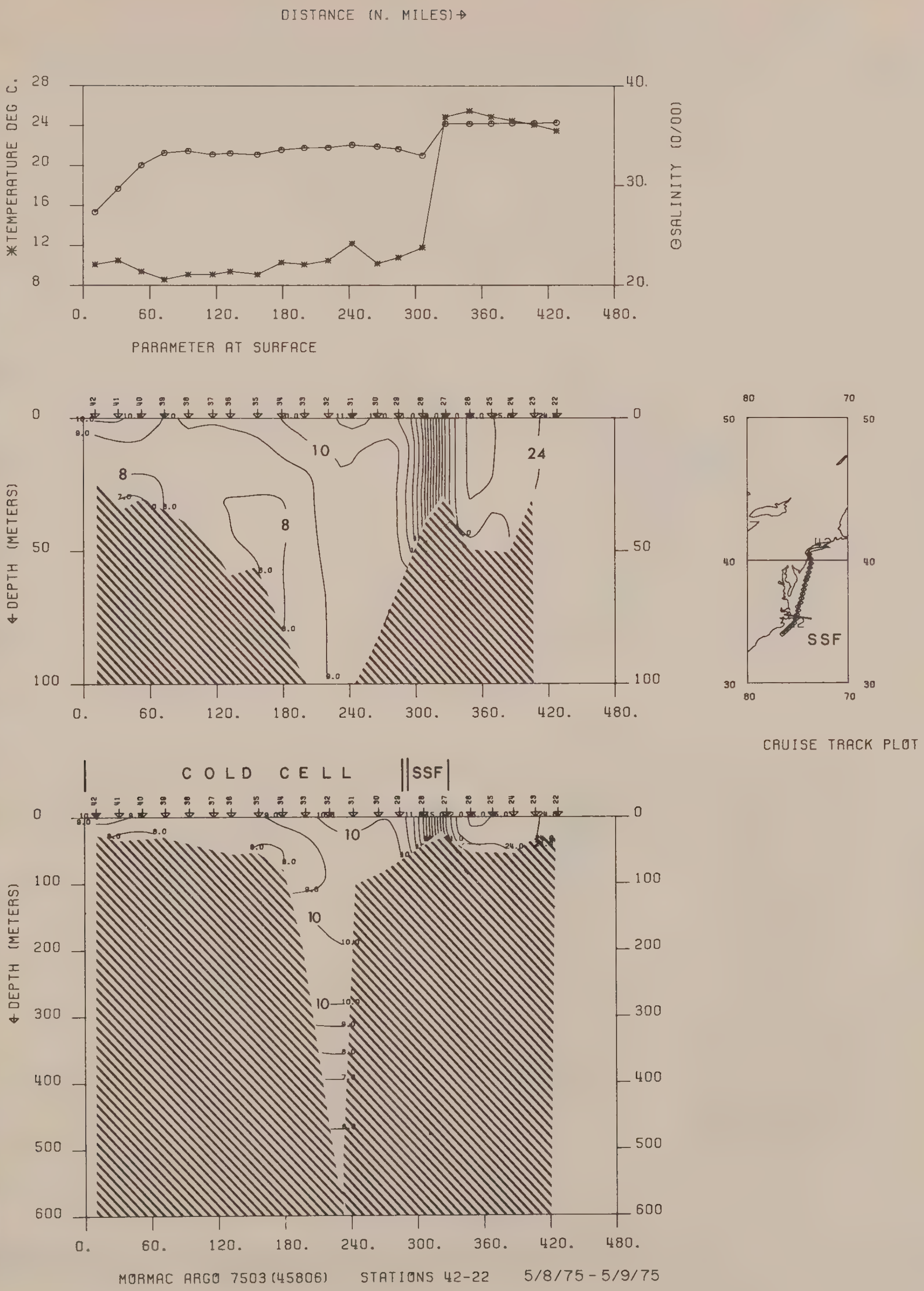
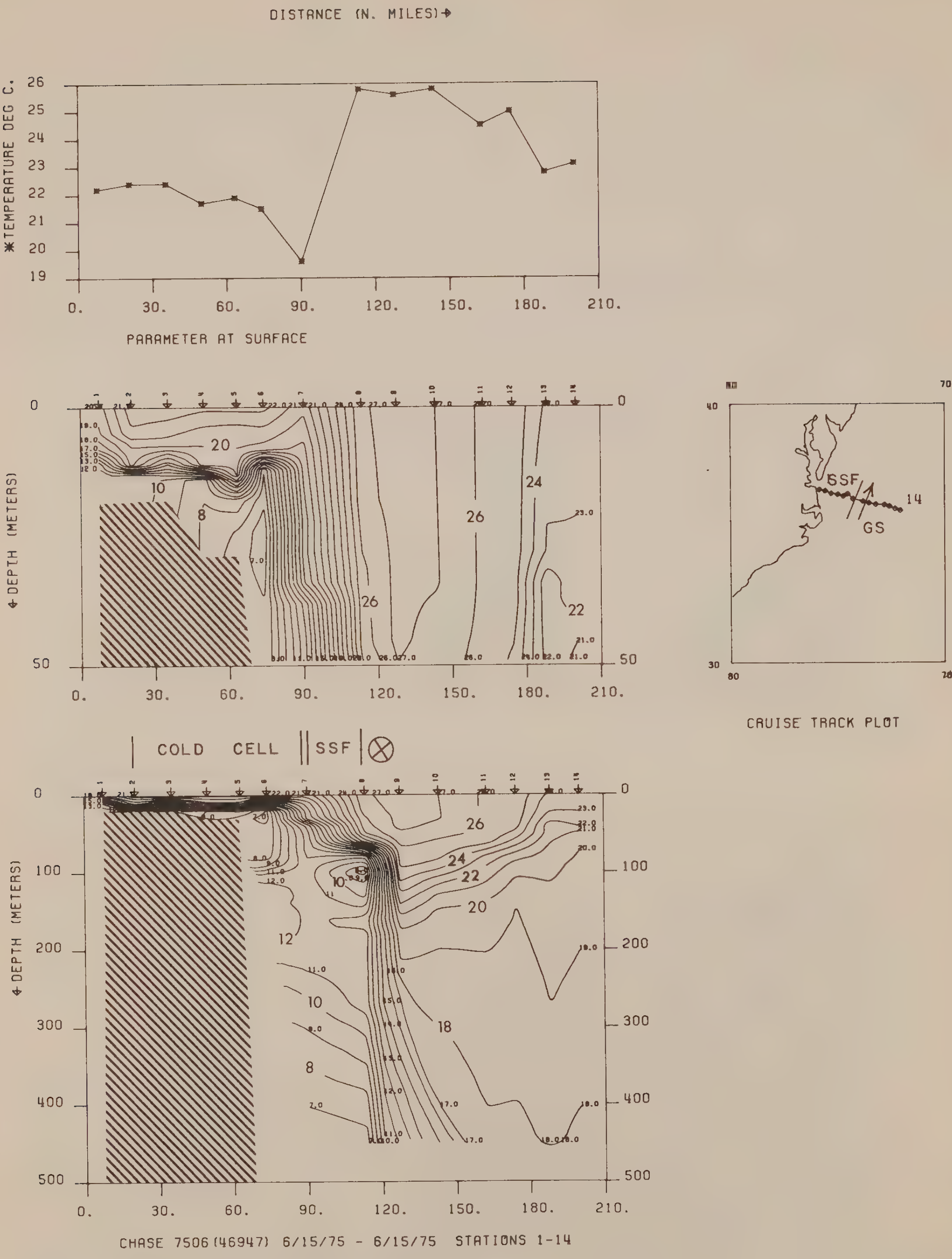
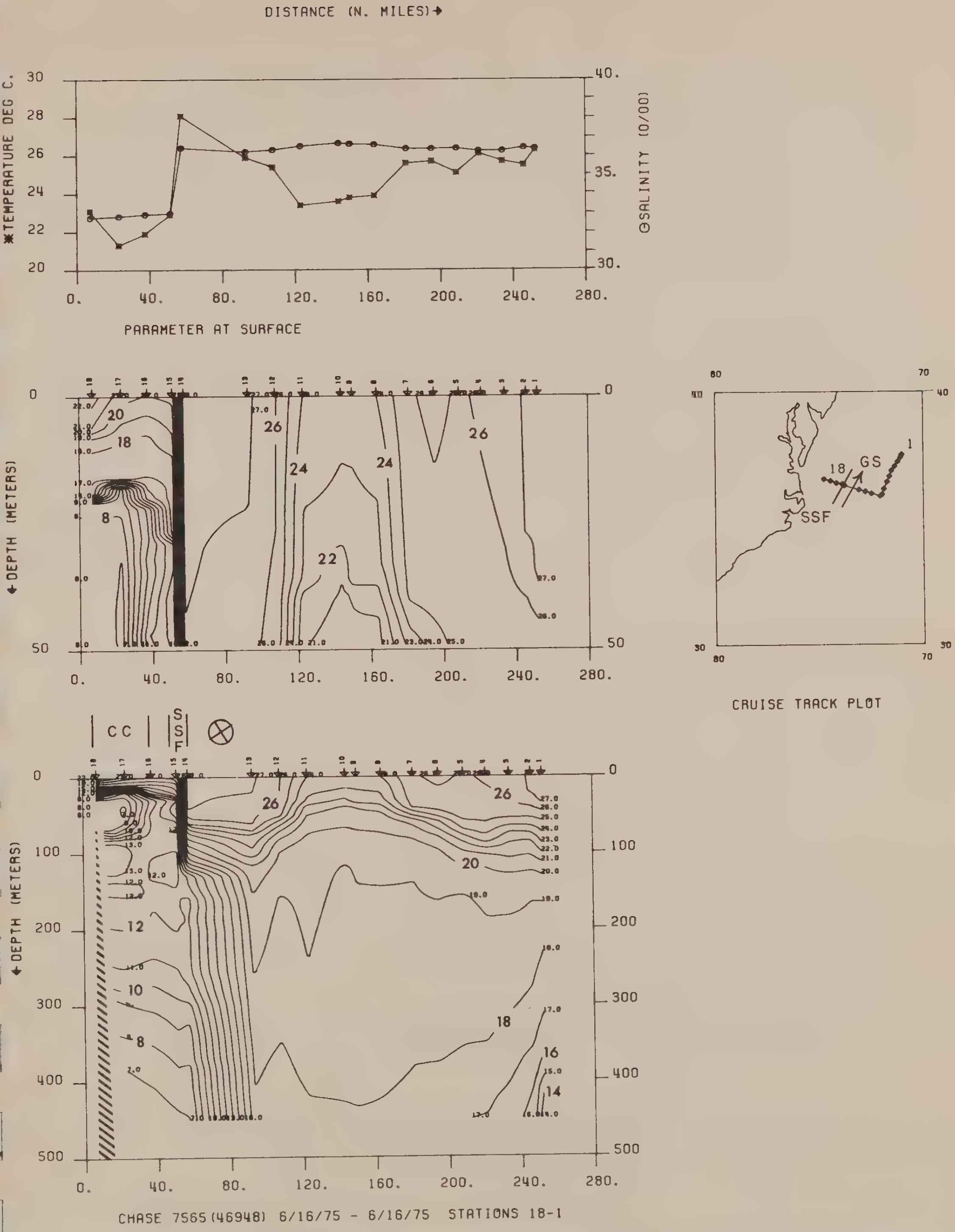
Appendix Figure 31.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Santa Cruz*—9-10 April 1975.



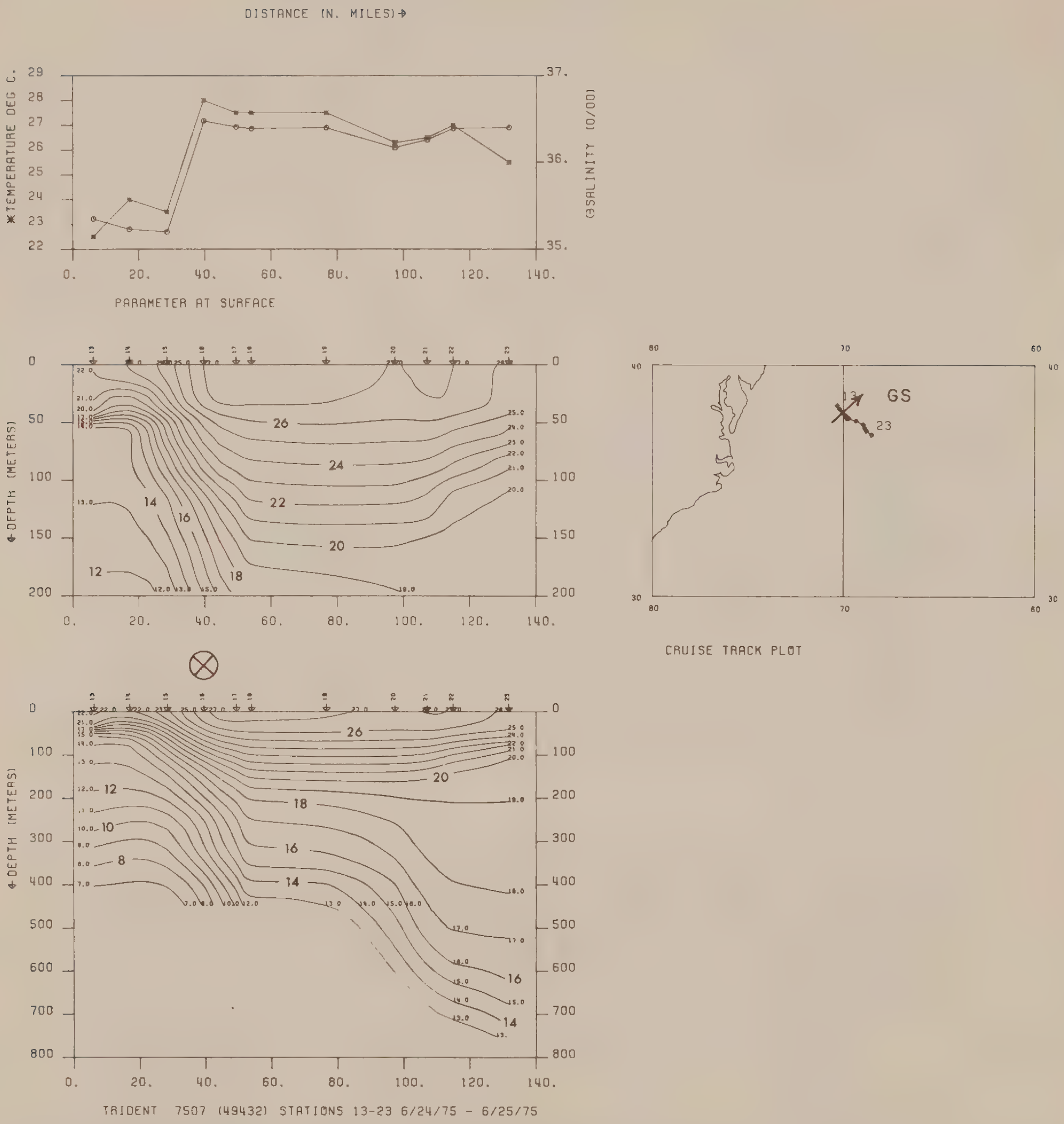
Appendix Figure 32.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Delta Sud*—2 January 1975.



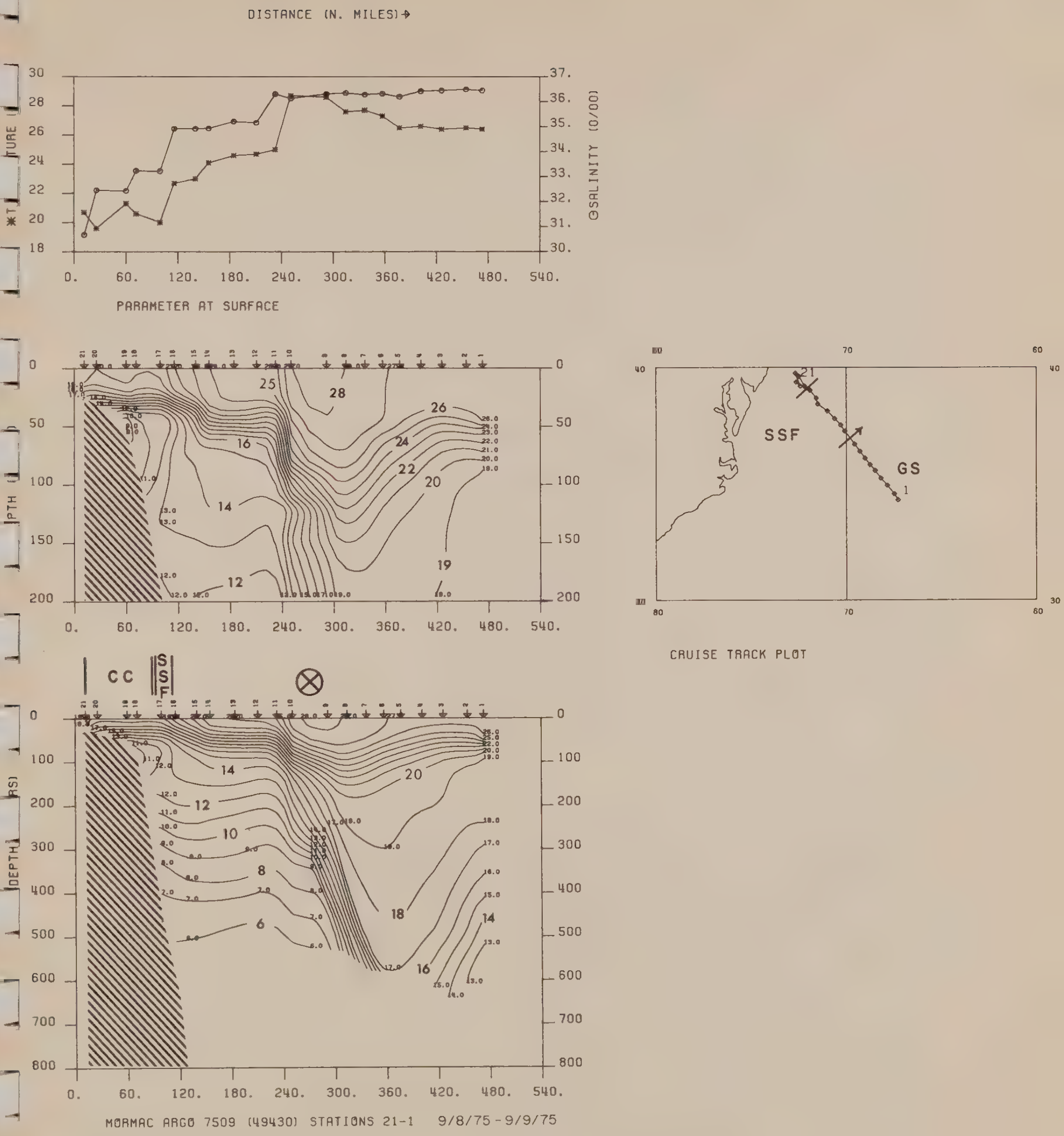
Appendix Figure 33.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 50 and 500 m. *Chase*—15 June 1975.



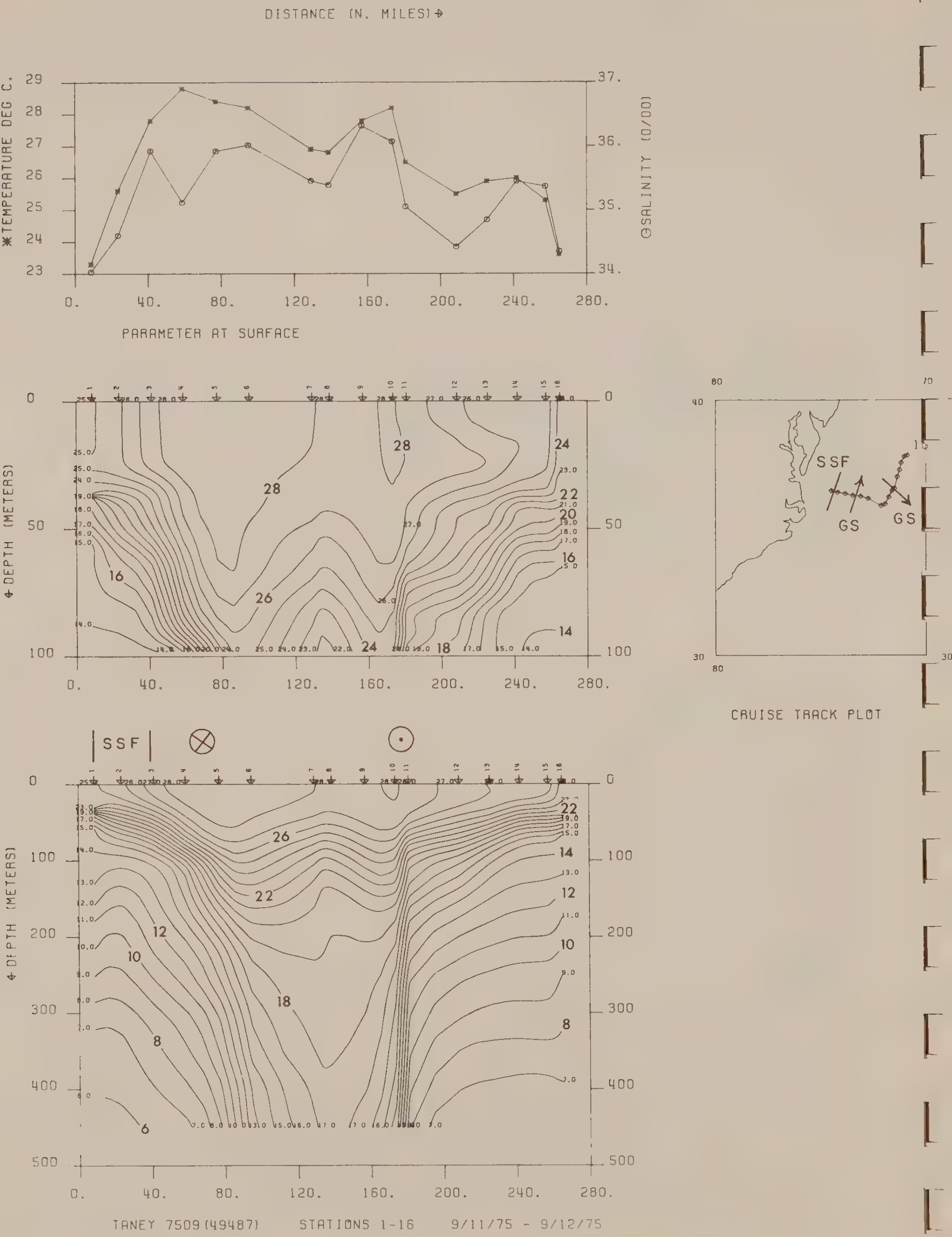
Appendix Figure 34.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 50 and 500 m. *Chase*—16 June 1975.



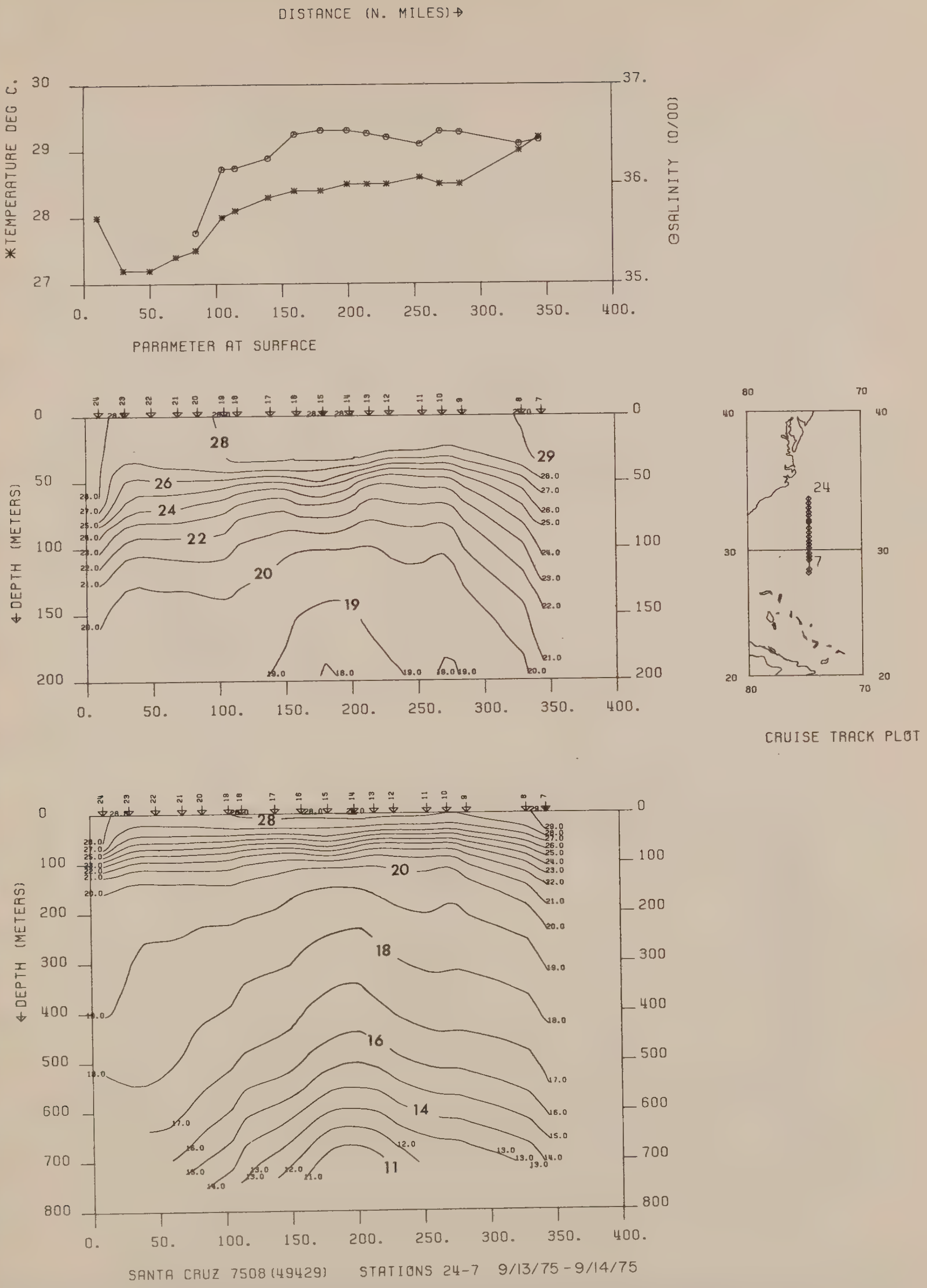
Appendix Figure 35.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Trident*—24-25 June 1975.



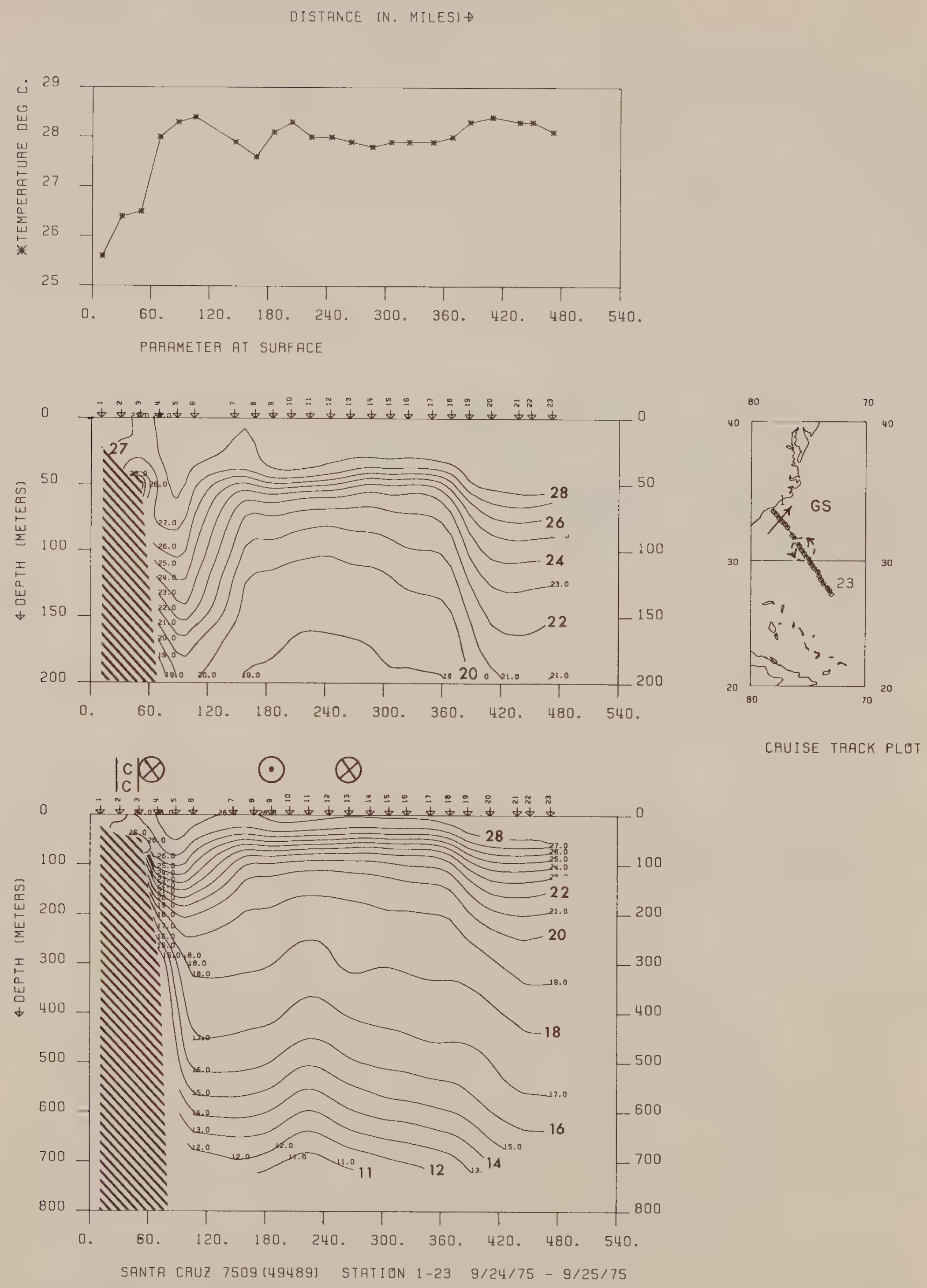
ndix Figure 36.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Mormac Argo*—8-9 September 1975.



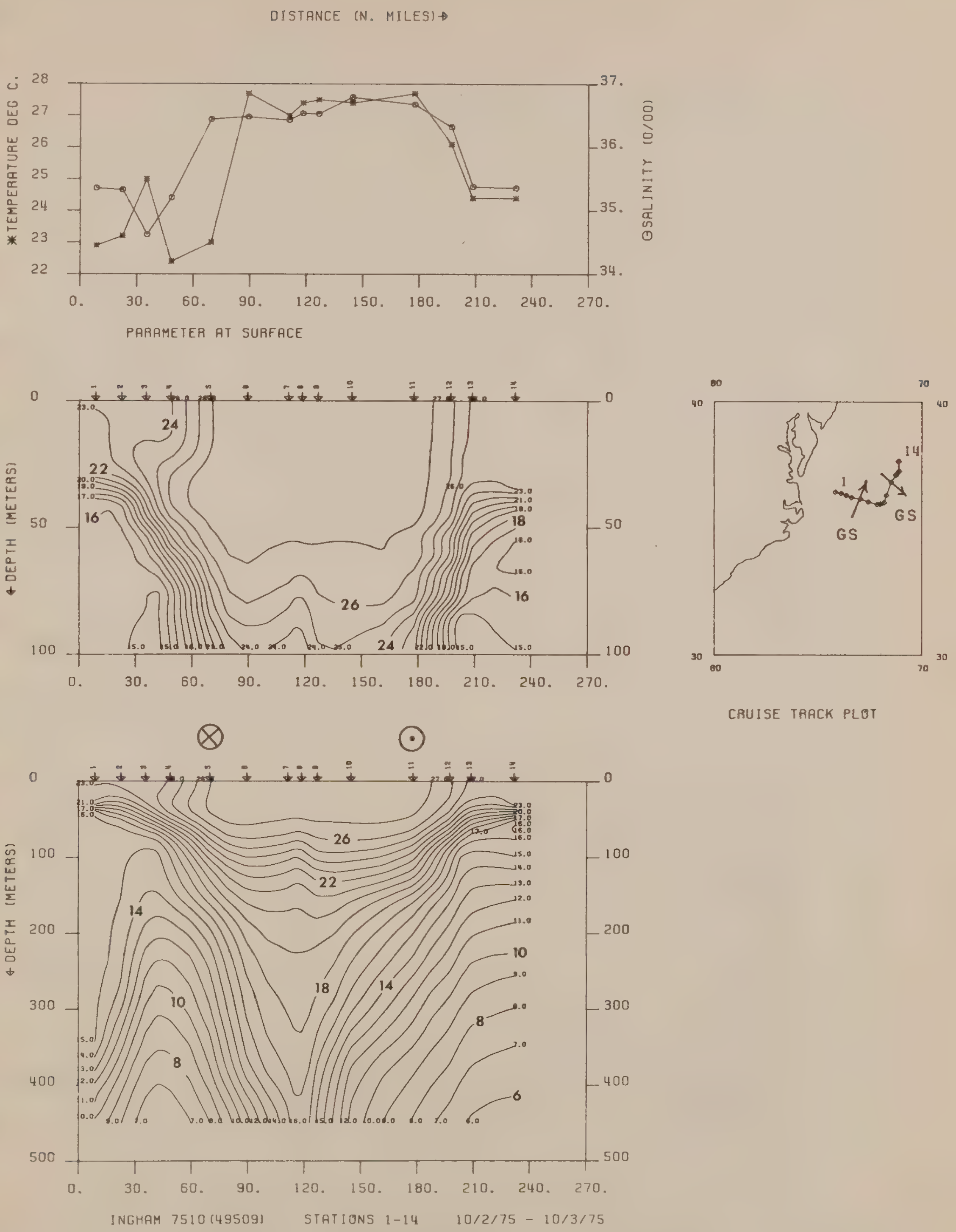
Appendix Figure 37.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 100 and 500 m. *Taney*—11-12 September 1975.



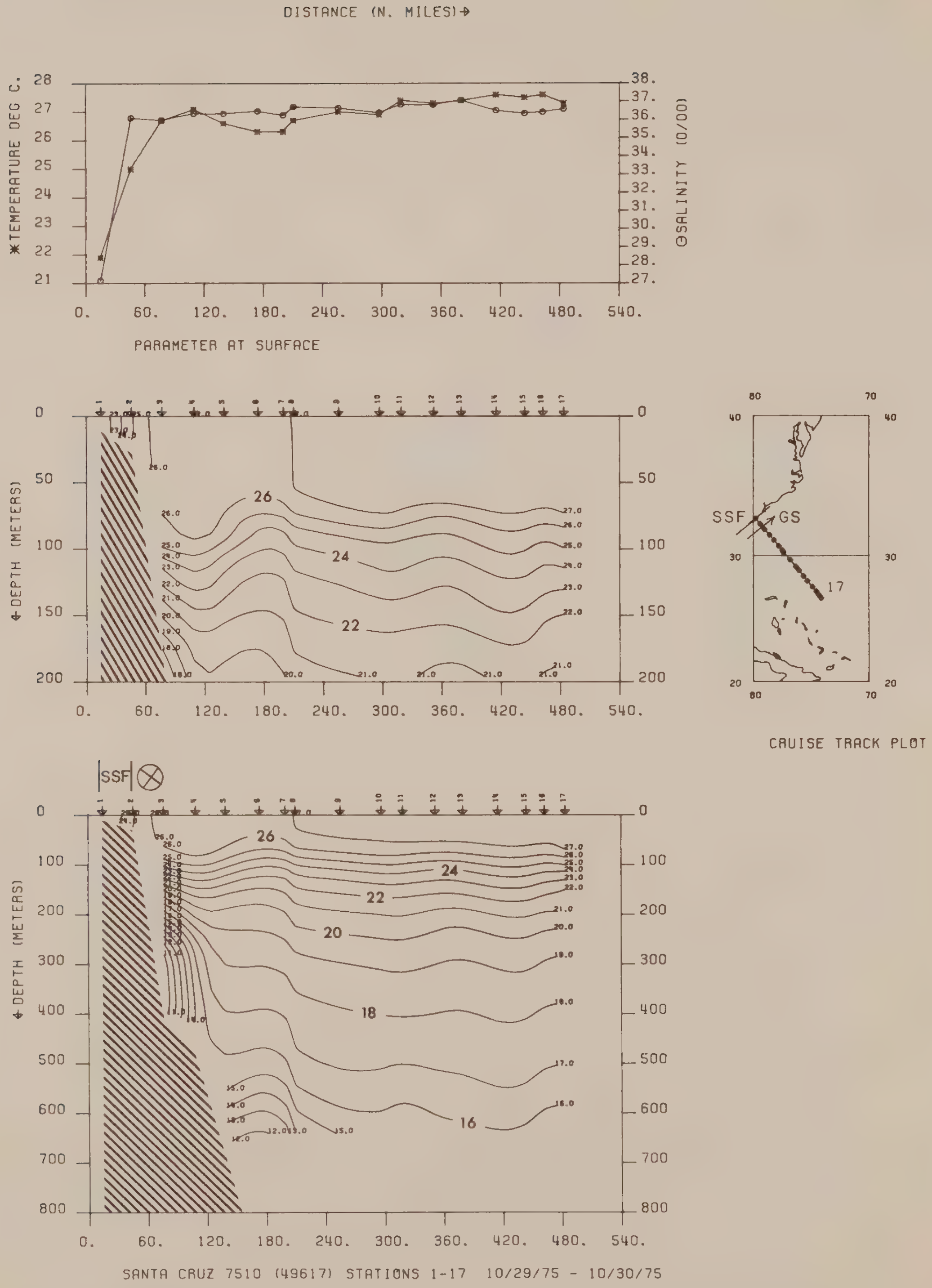
Appendix Figure 38.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Santa Cruz*—13-14 September 1975.



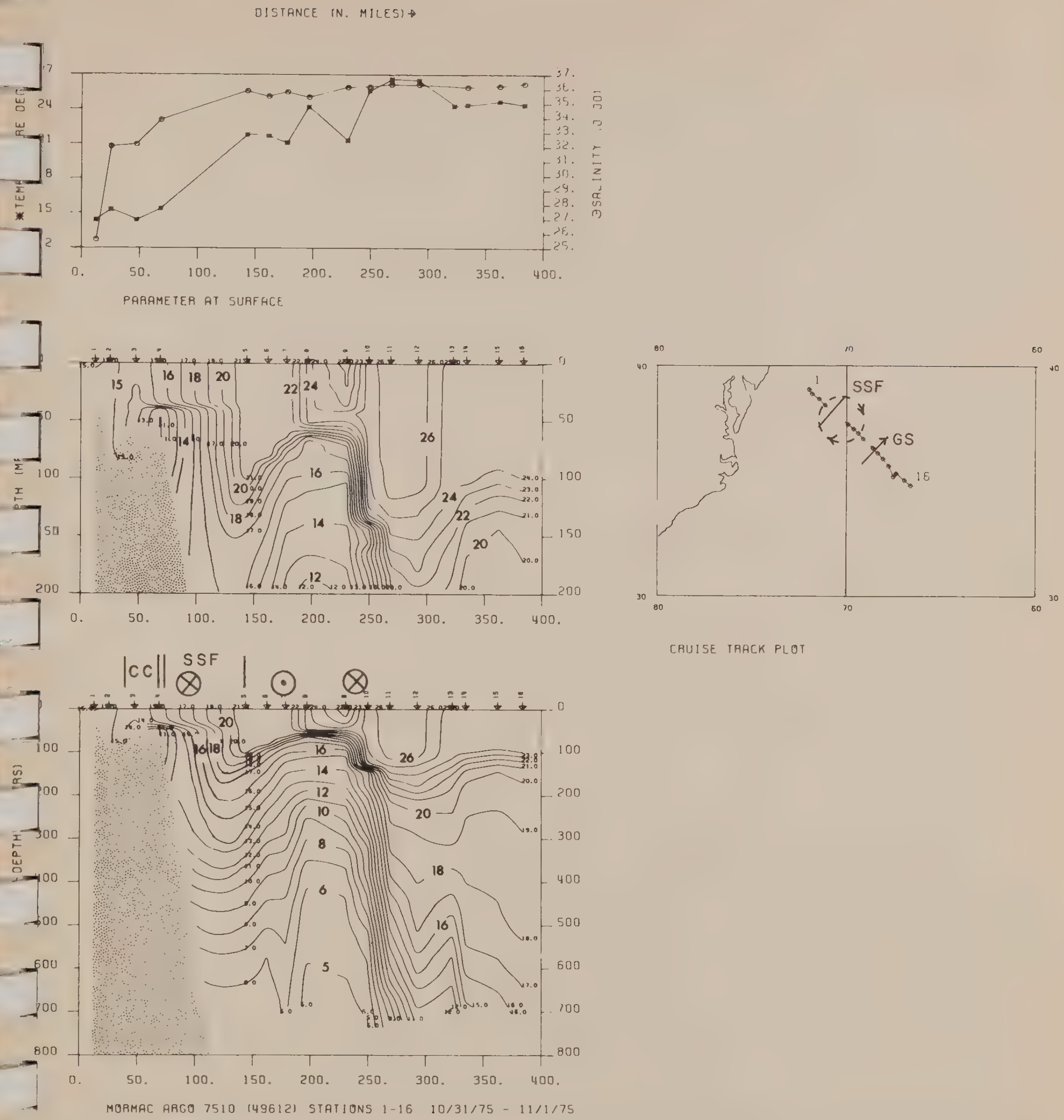
Appendix Figure 39.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Santa Cruz*—24-25 September 1975.



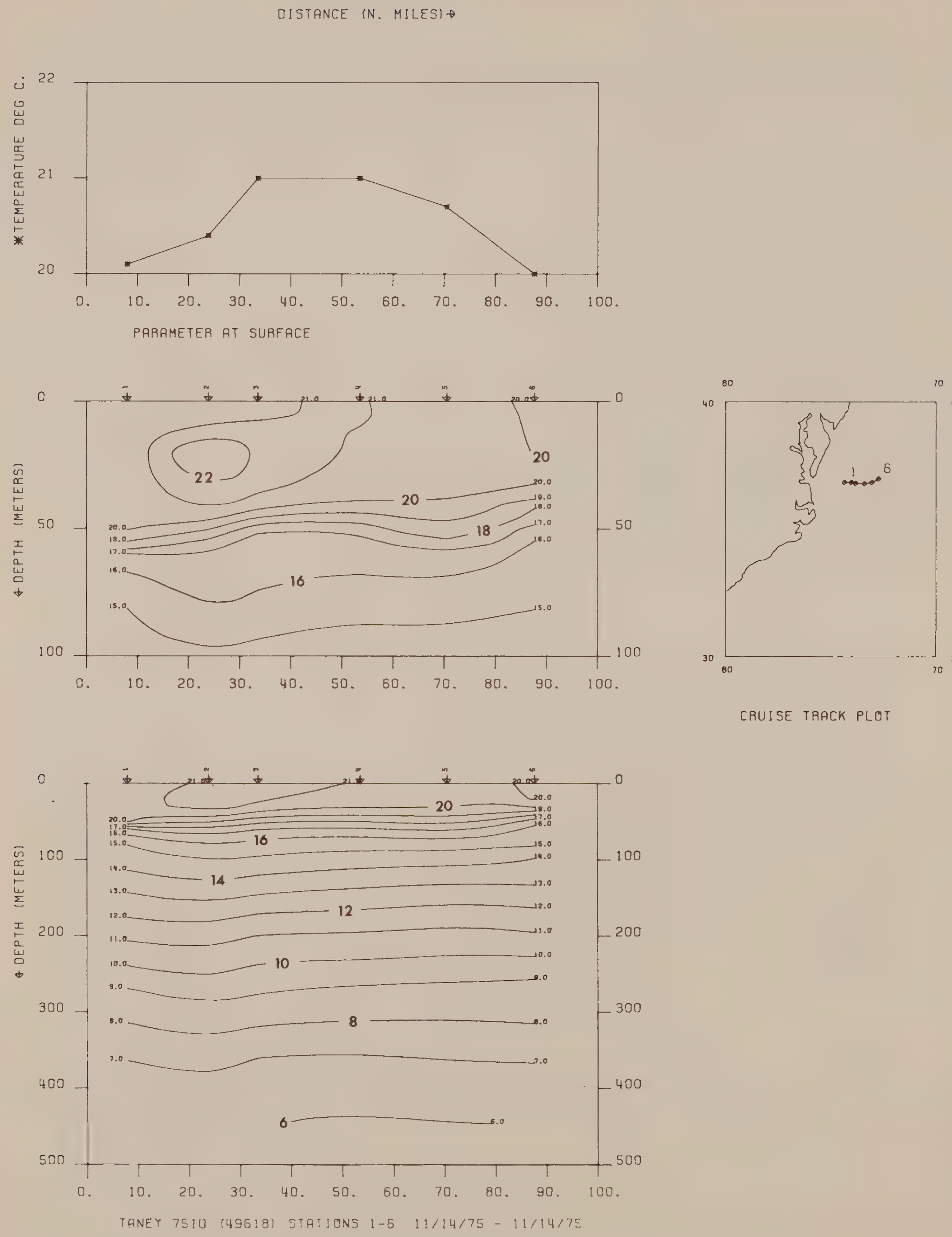
Appendix Figure 40.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 100 and 500 m. *Ingham*—2-3 October 1975.



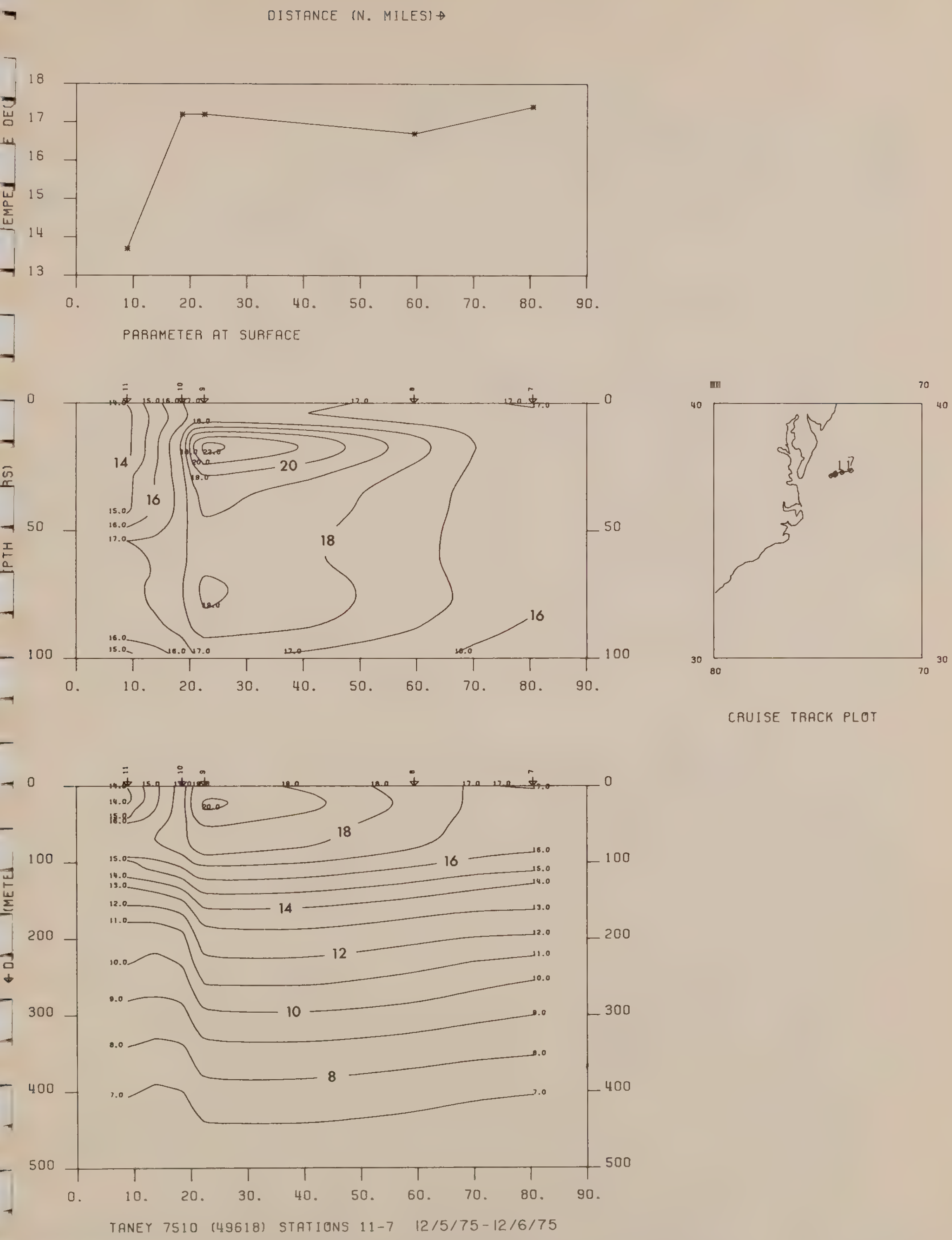
Appendix Figure 41.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Santa Cruz*—29-30 October 1975.



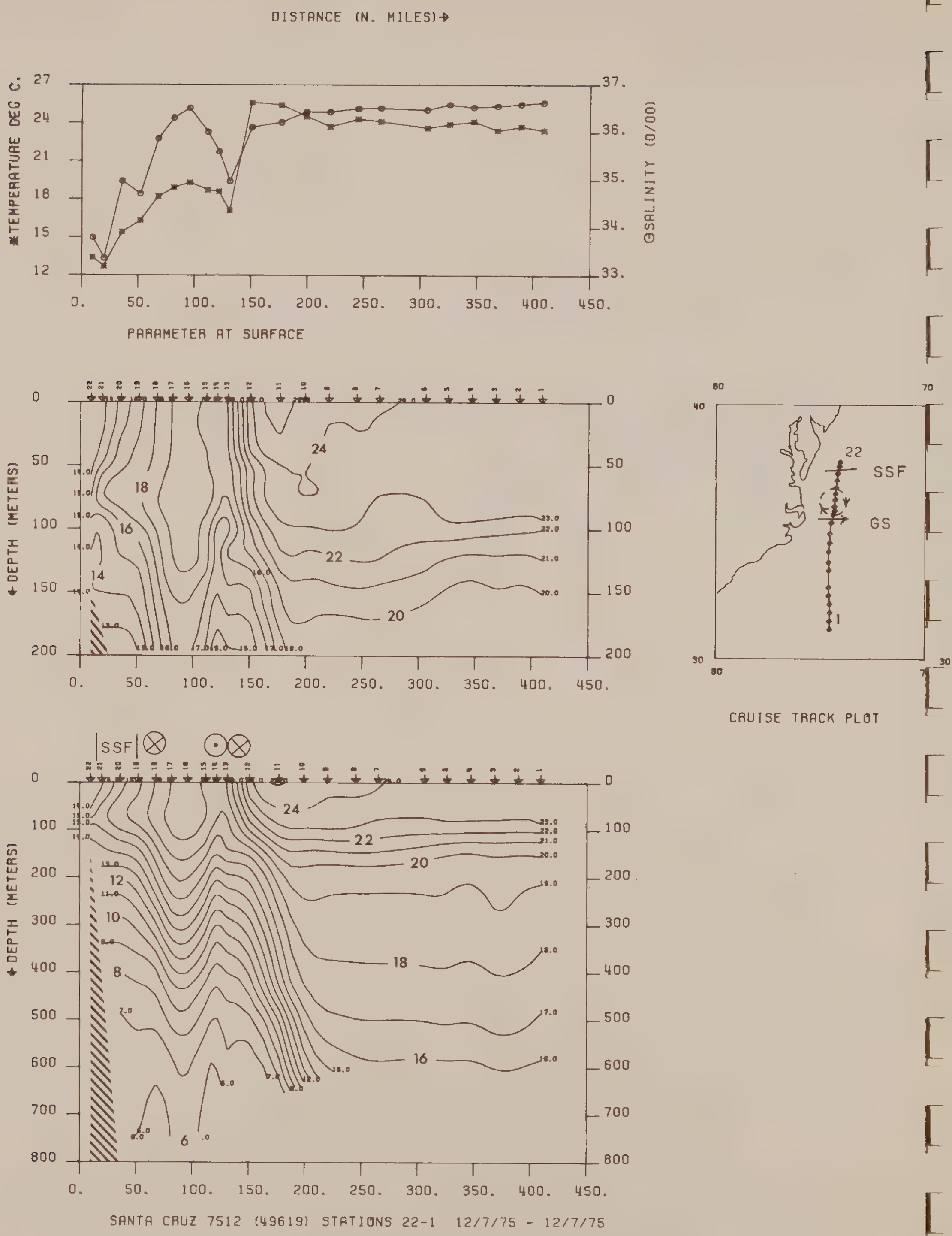
Appendix Figure 42.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Mormac Argo*—31 October-1 November 1975.



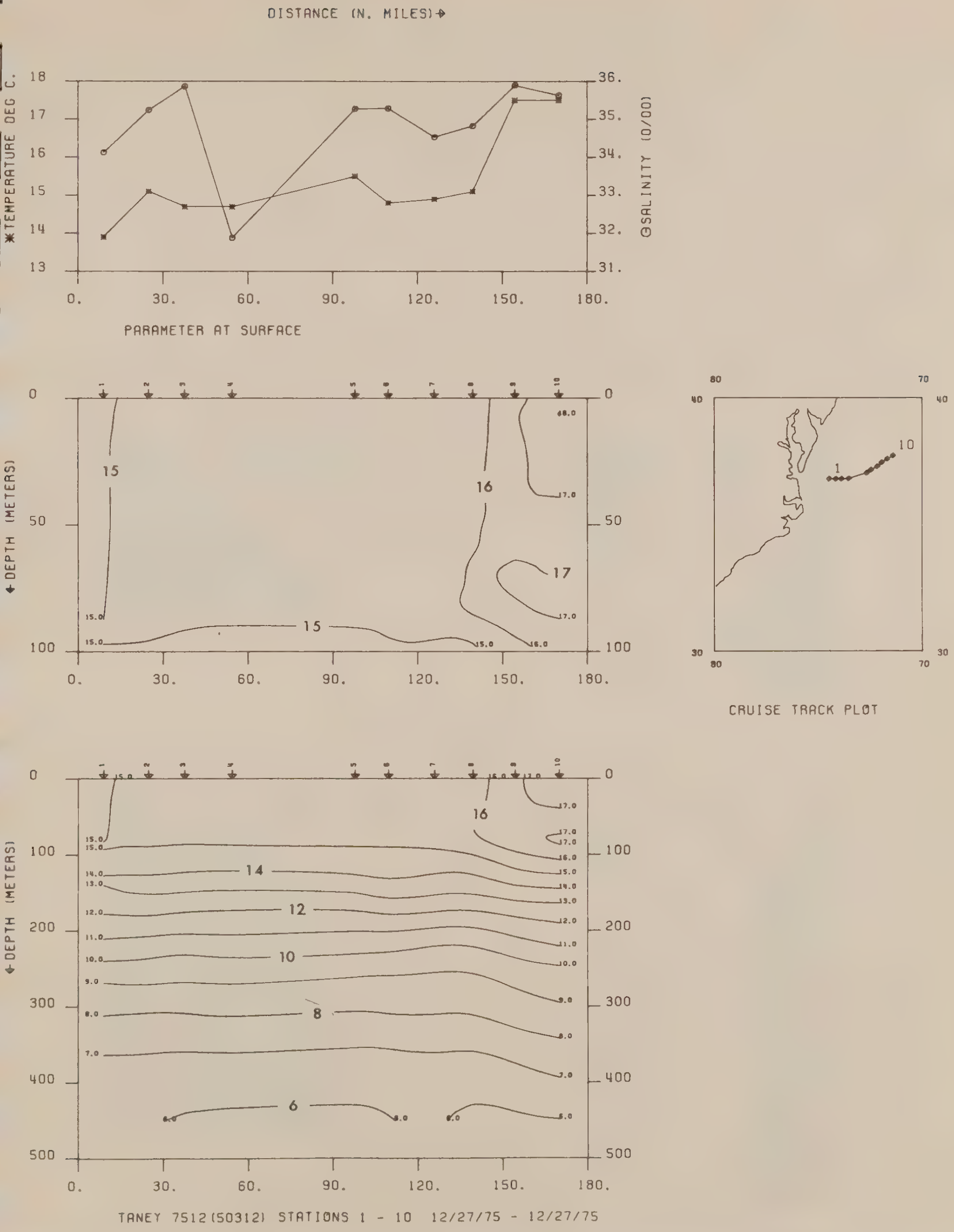
Appendix Figure 43.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 100 and 500 m. *Taney*—14 November 1975.



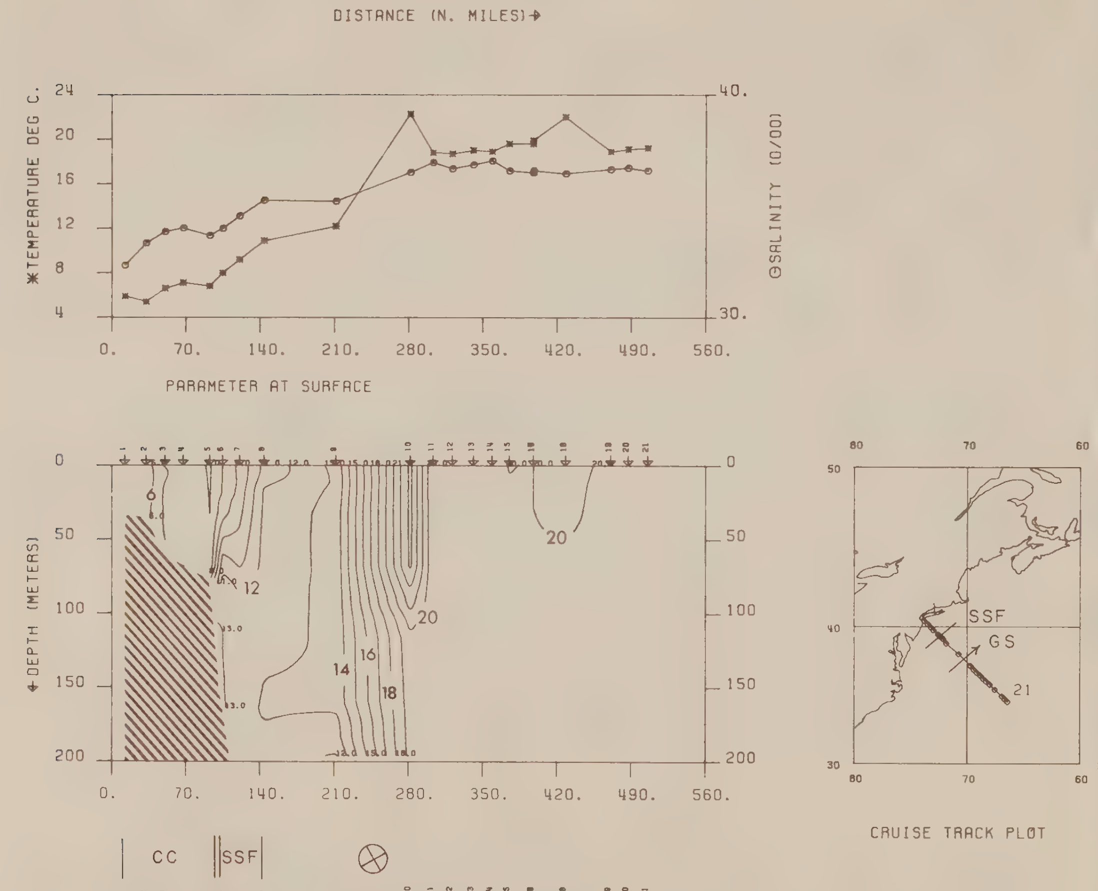
ppendix Figure 44.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 100 and 500 m. *Taney*—5-6 December 1975.



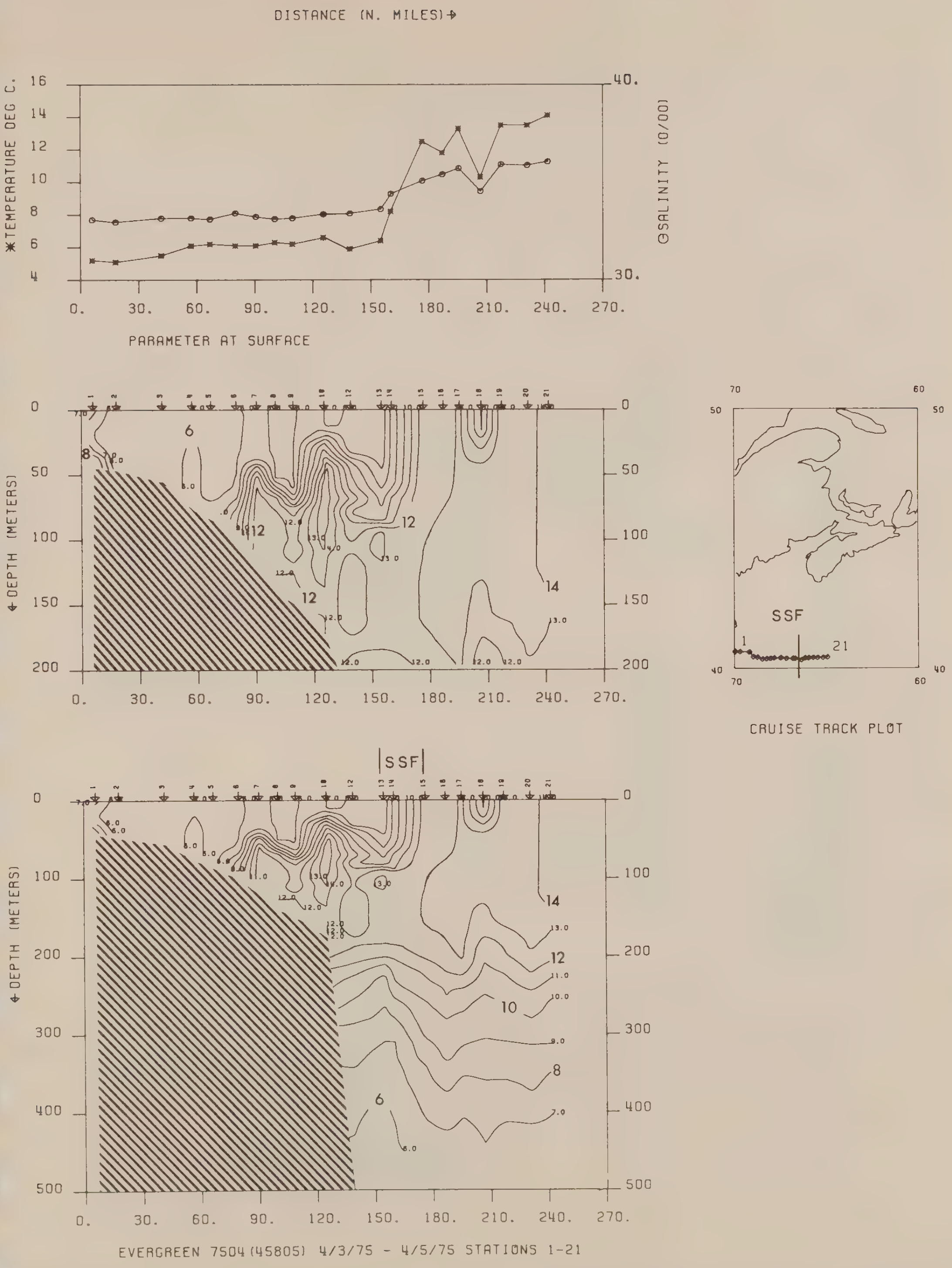
Appendix Figure 45.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Santa Cruz*—7 December 1975.



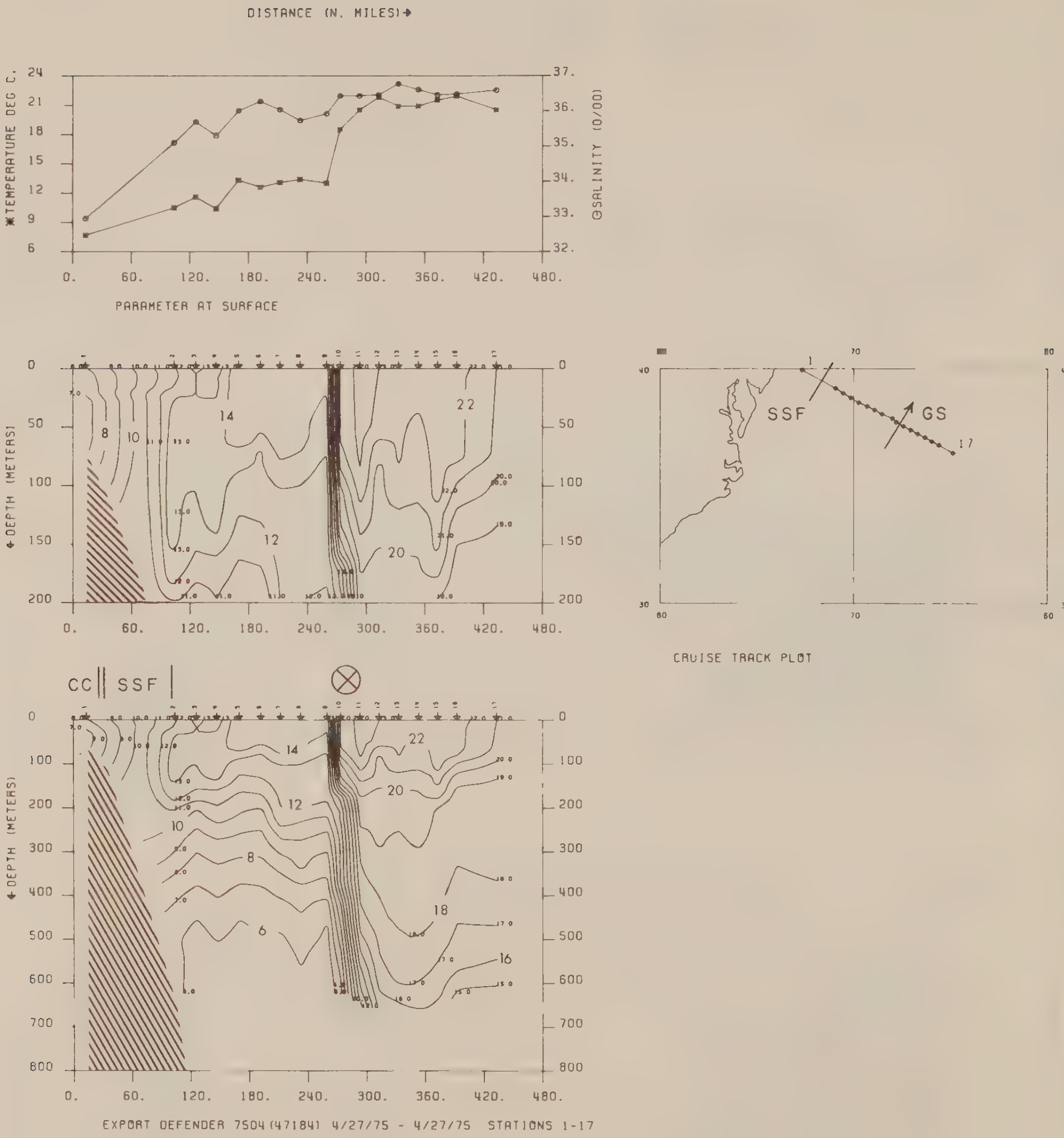
Appendix Figure 46.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 100 and 500 m. *Taney*—27 December 1975.



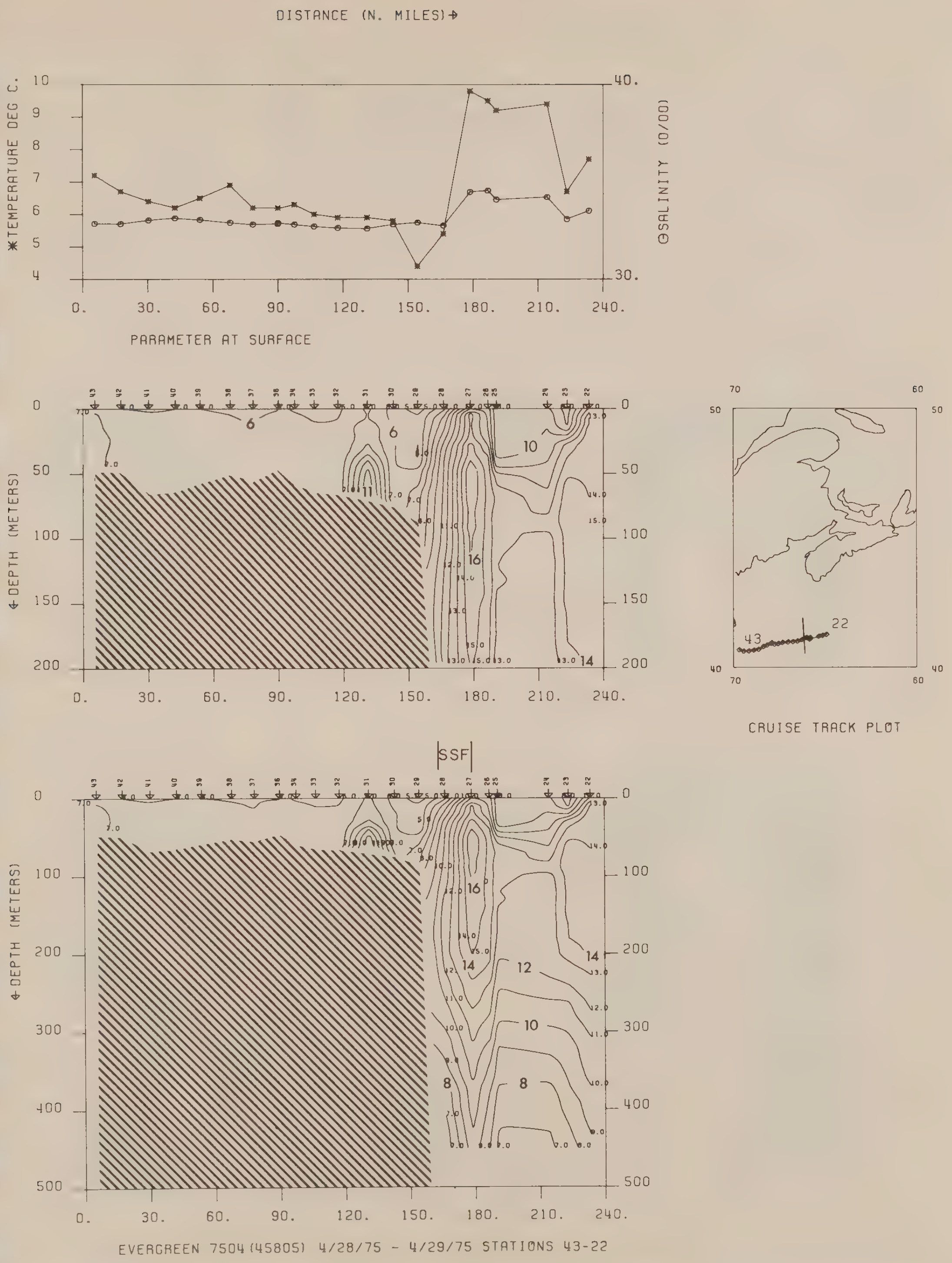
Appendix Figure 47.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Mormac Argo*—21-22 March 1975.



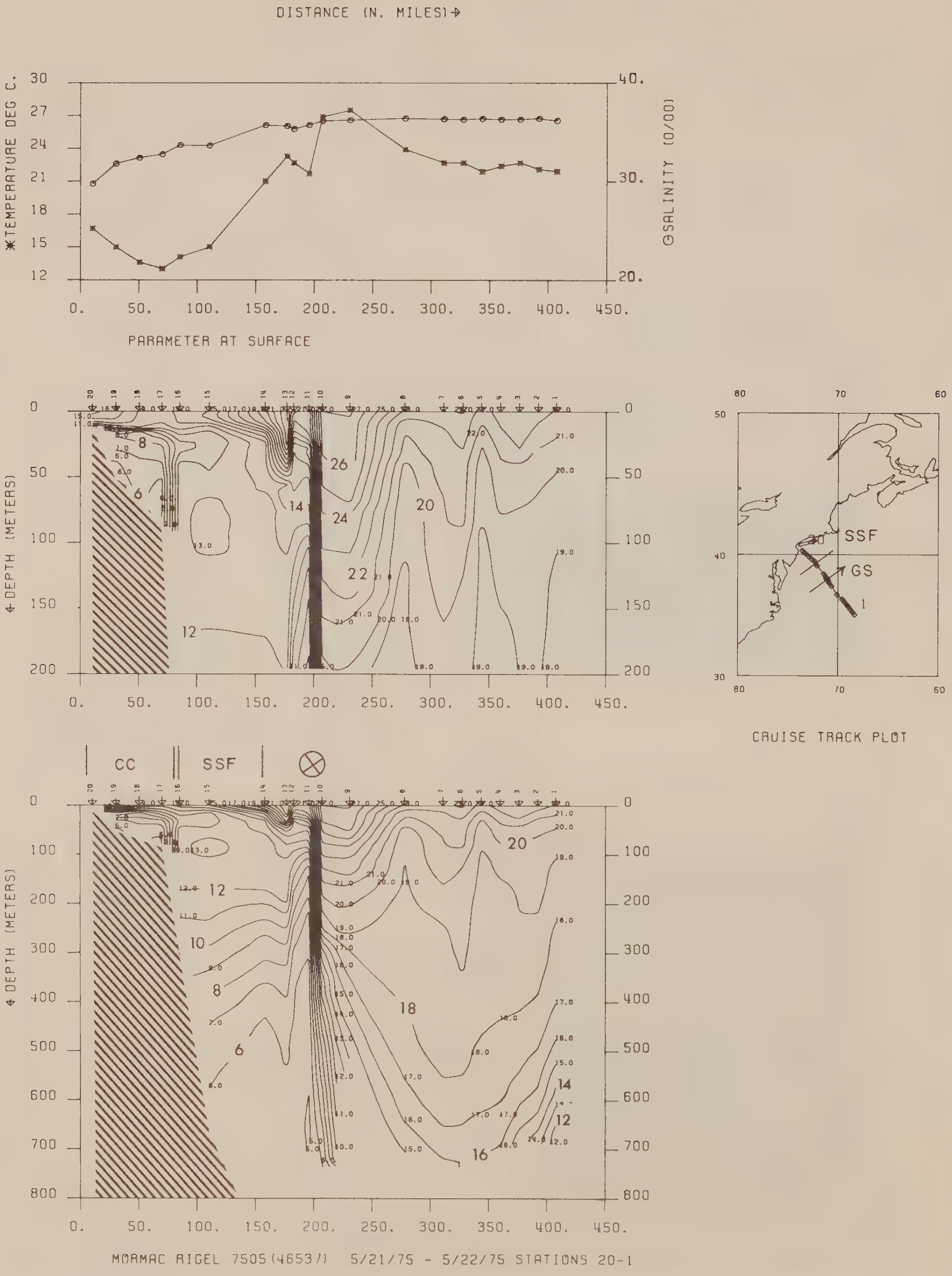
Appendix Figure 48.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 500 m. *Evergreen*—3-5 April 1975.



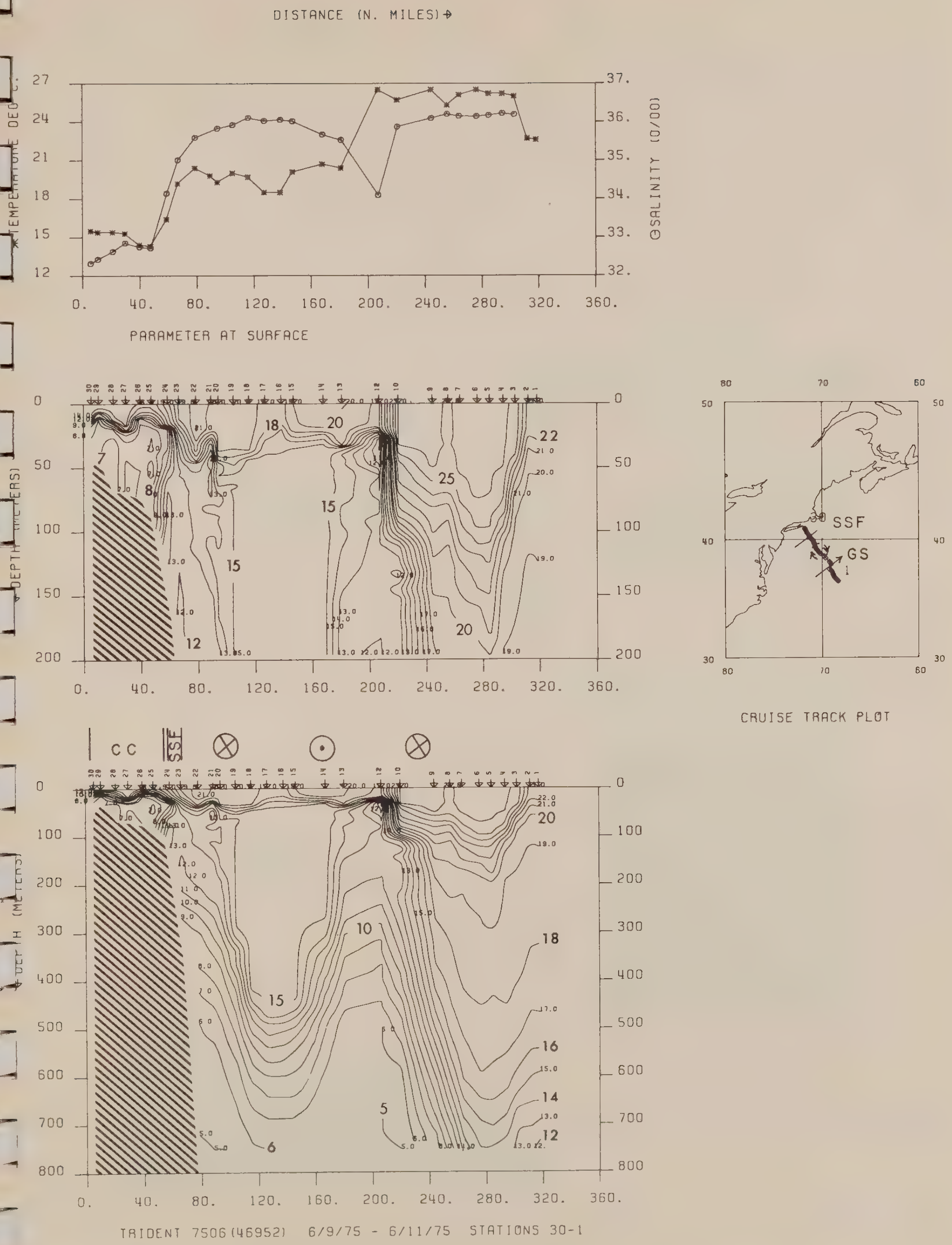
Appendix Figure 49.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Export Defender*—27 April 1975.



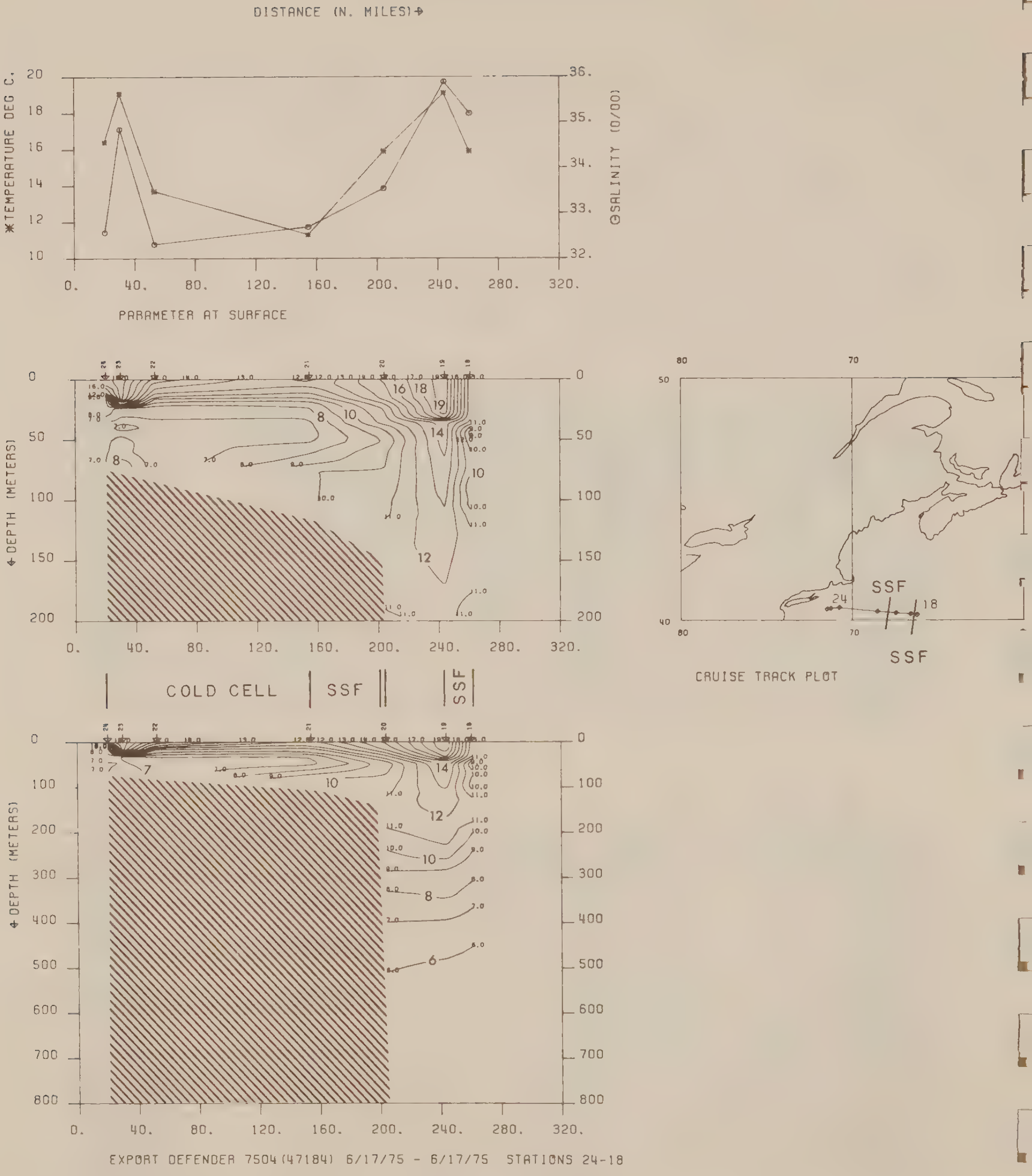
Appendix Figure 50.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 500 m. *Evergreen*—28-29 April 1975.



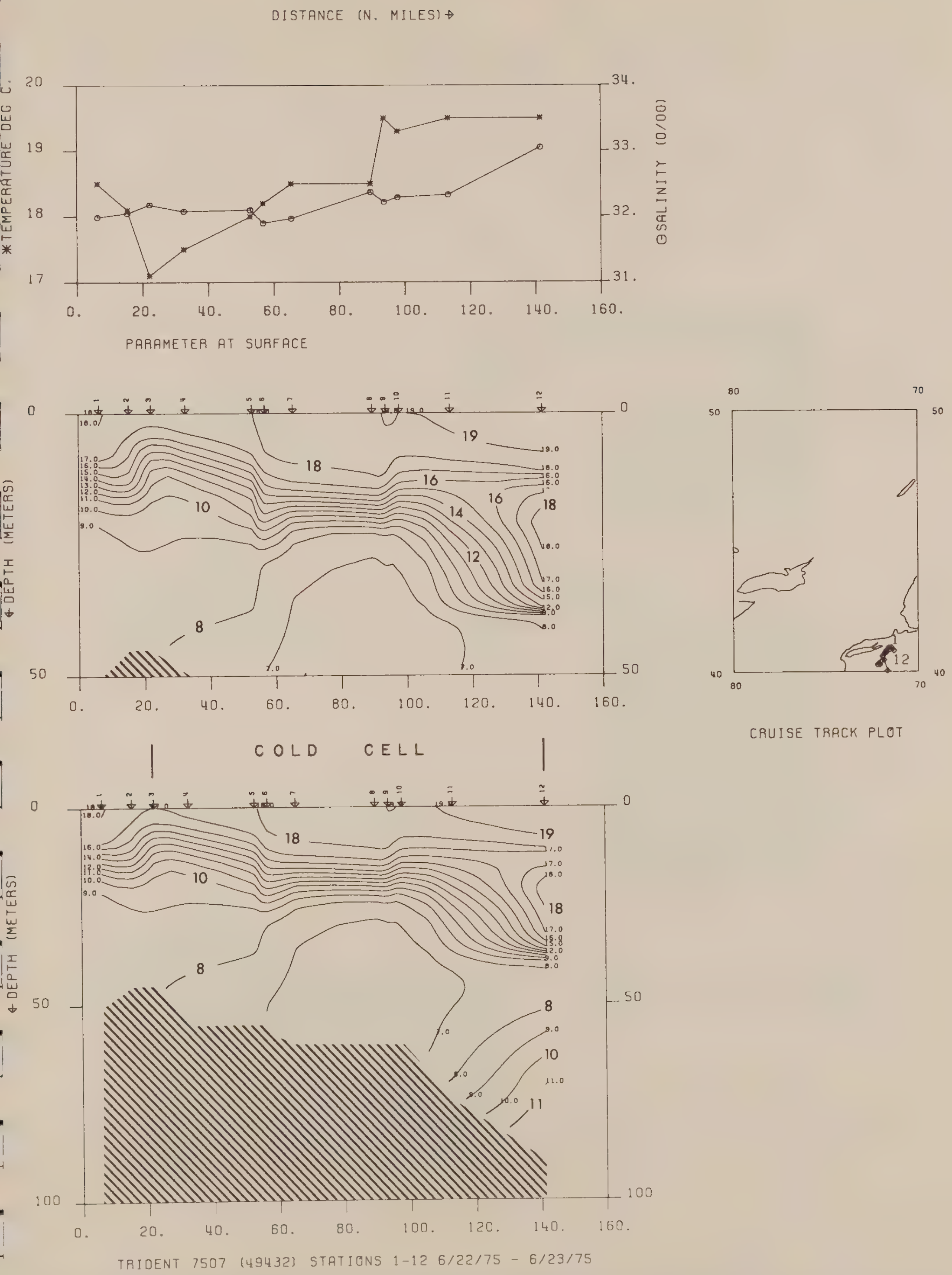
Appendix Figure 51.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Mormac Rigel*—21-22 May 1975.



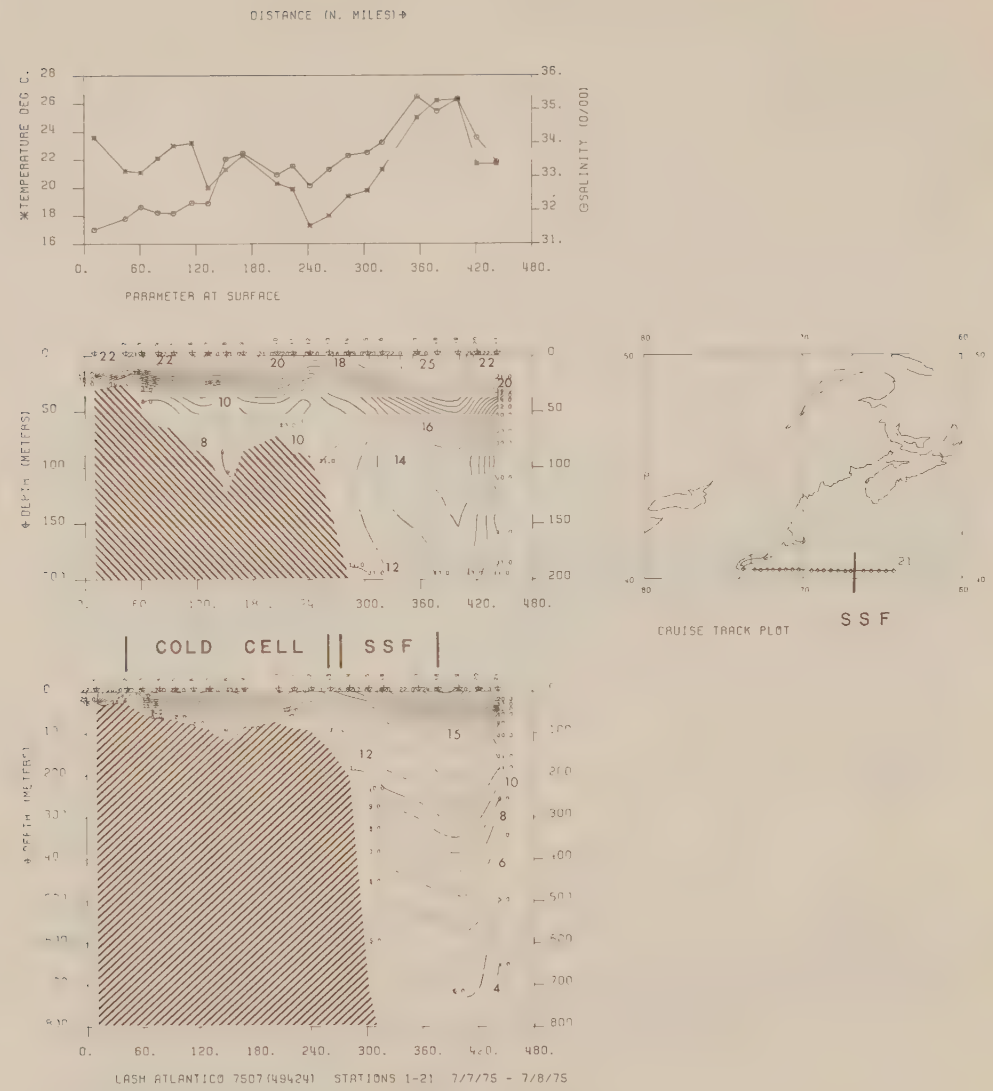
Appendix Figure 52.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Trident*—9-11 June 1975.



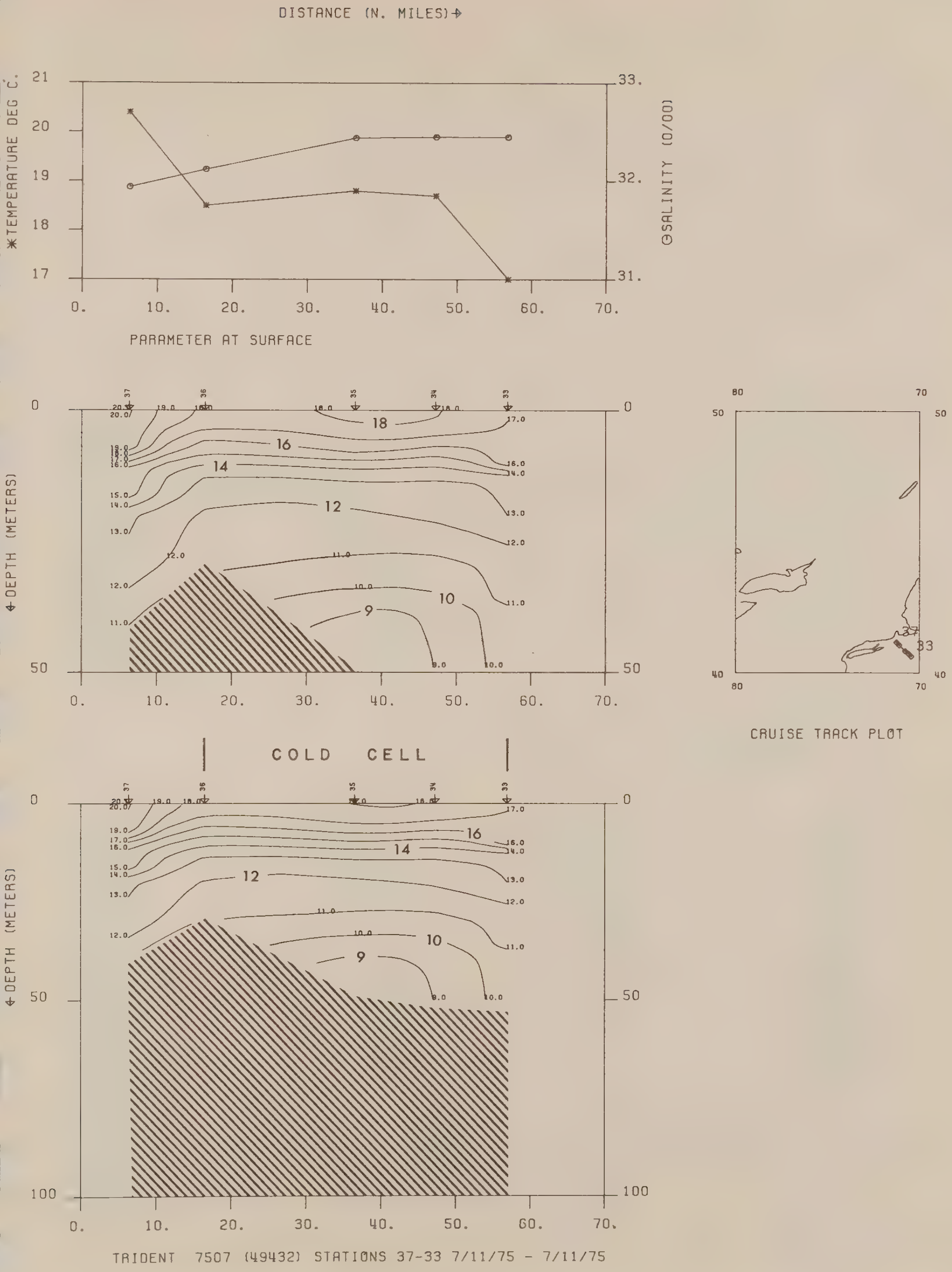
Appendix Figure 53.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Export Defender*—17 June 1975.



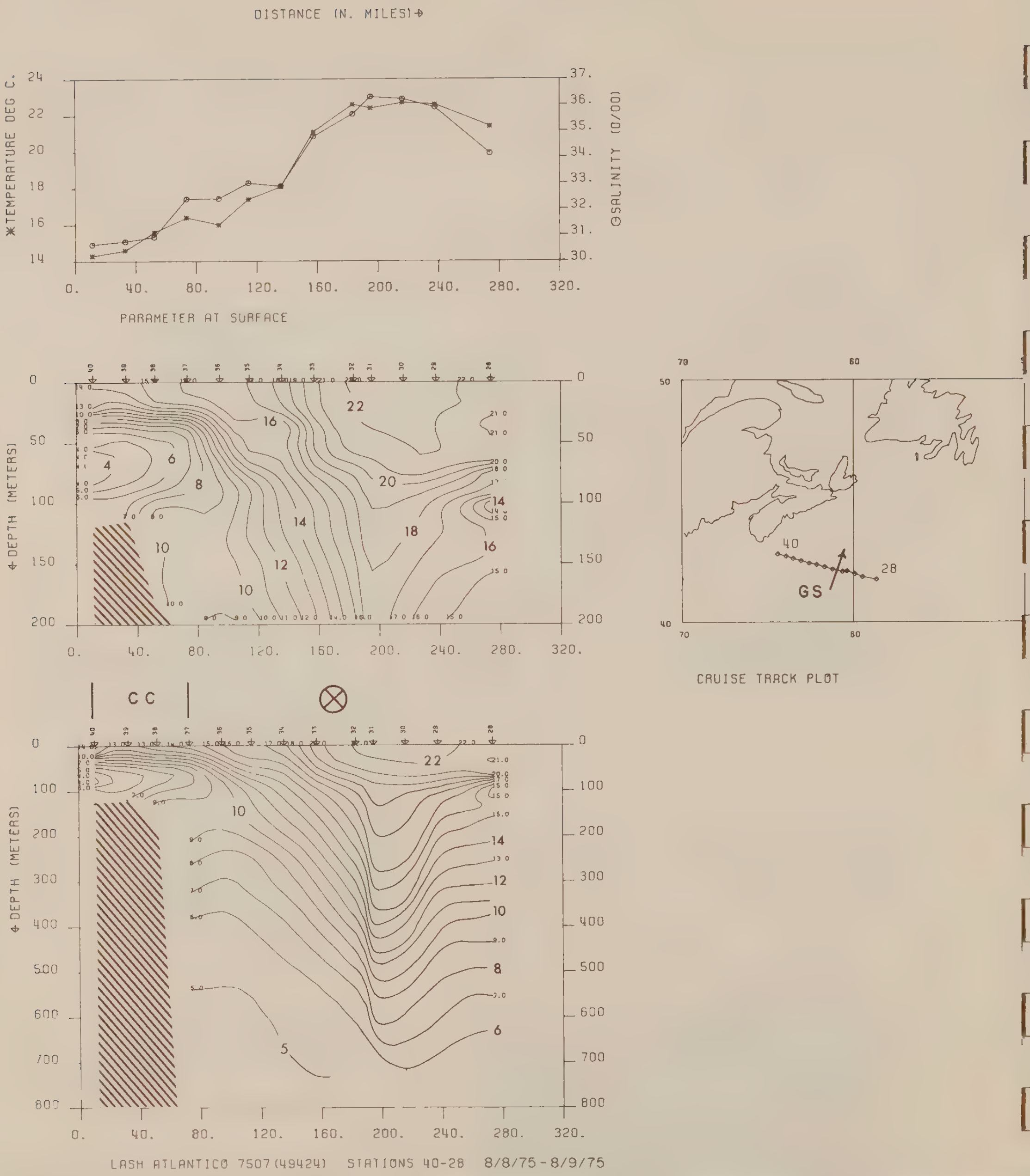
Appendix Figure 54.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 50 and 100 m. *Trident*—22-23 June 1975.



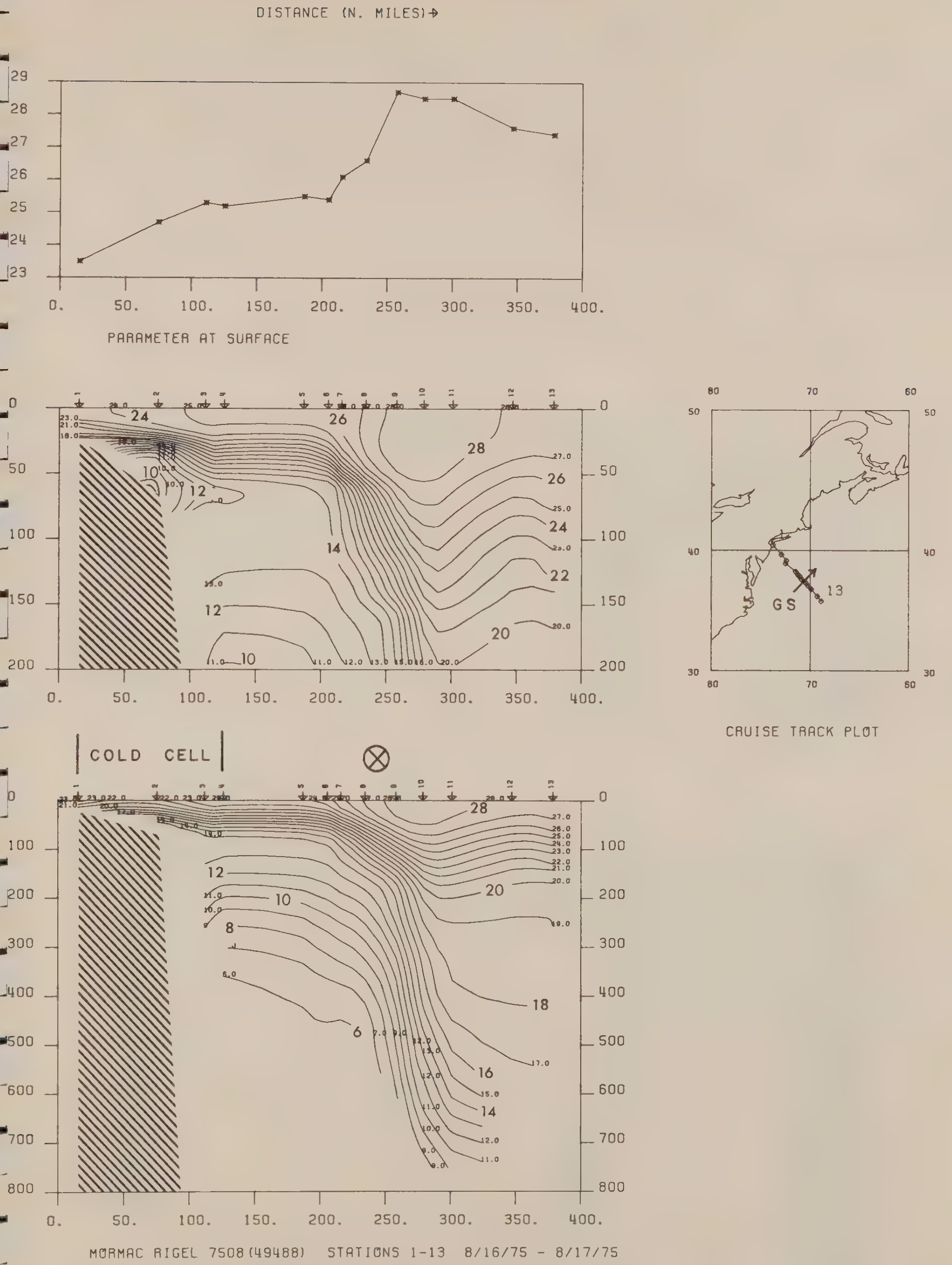
Appendix Figure 55.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Lash Atlantico*—7-8 July 1975.



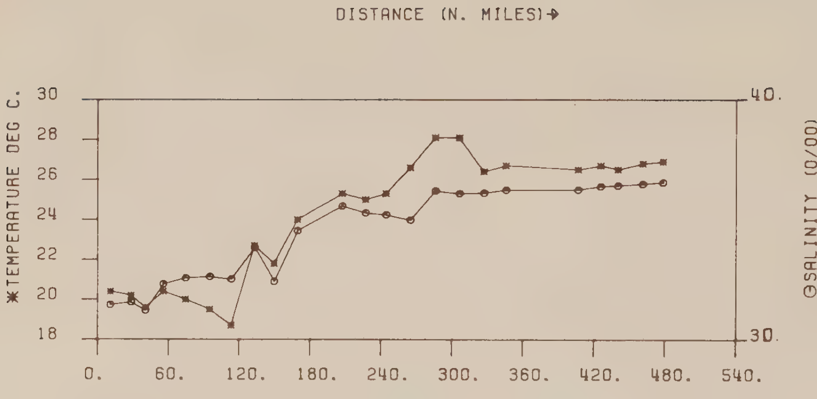
Appendix Figure 56.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 50 and 100 m. *Trident*—11 July 1975.



Appendix Figure 57.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribut of temperature (°C) in the upper 200 and 800 m. *Lash Atlantico*—8-9 August 1975.



Appendix Figure 58.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Mormac Rigel*—16-17 August 1975.



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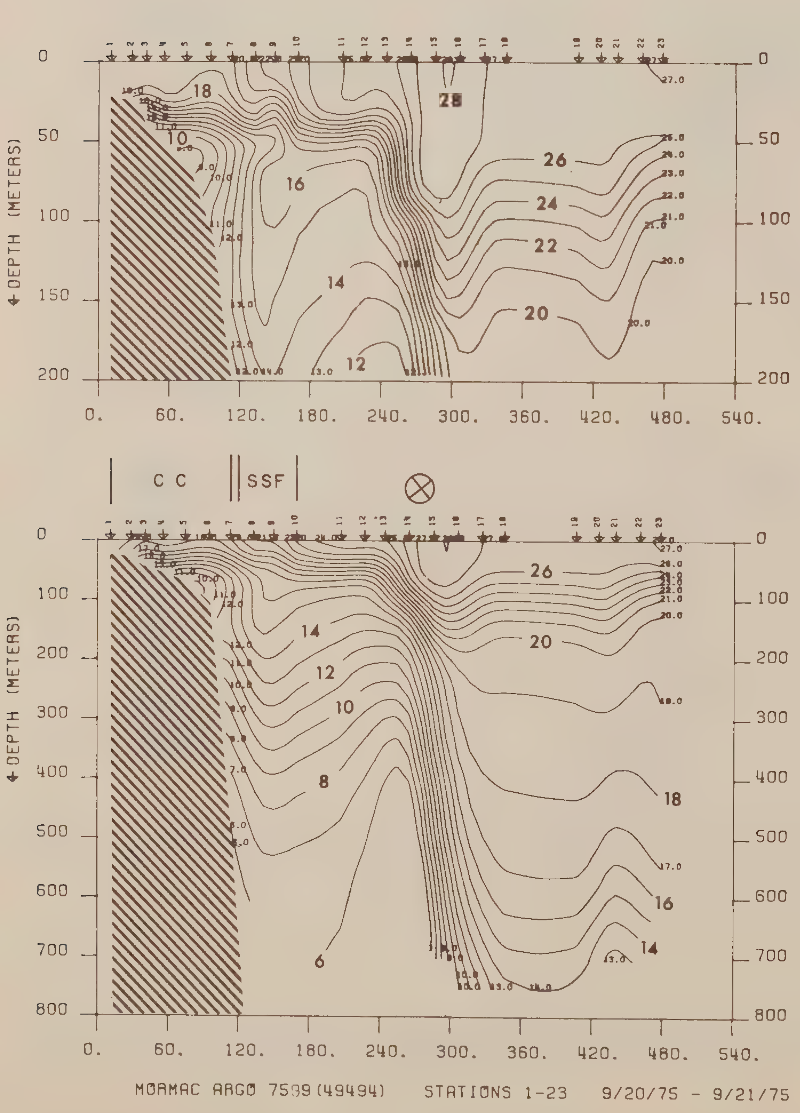

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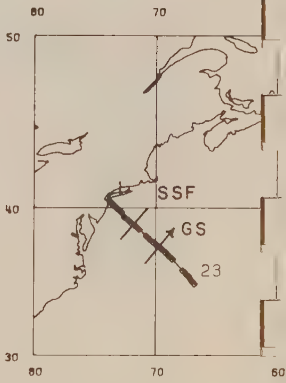
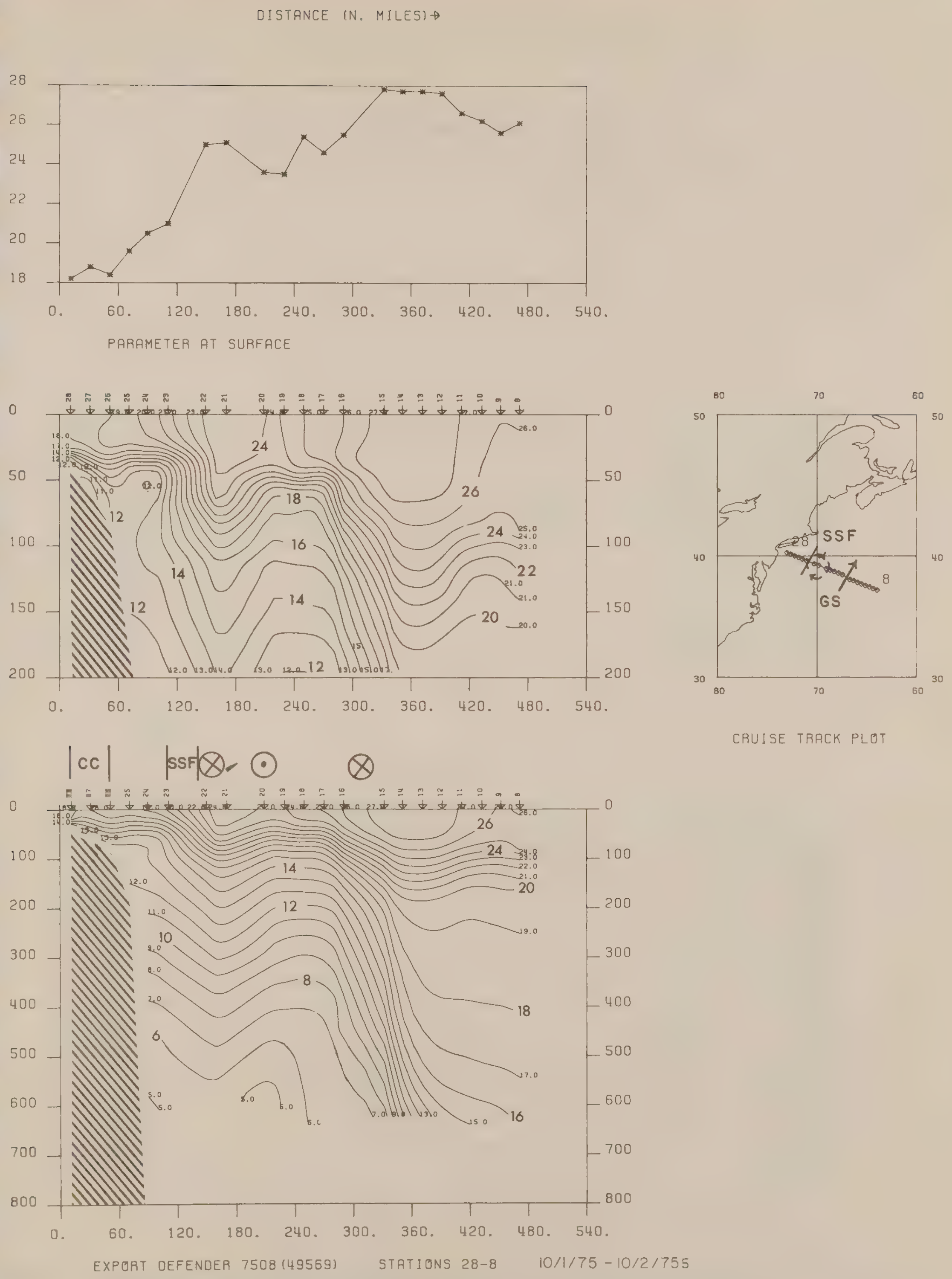
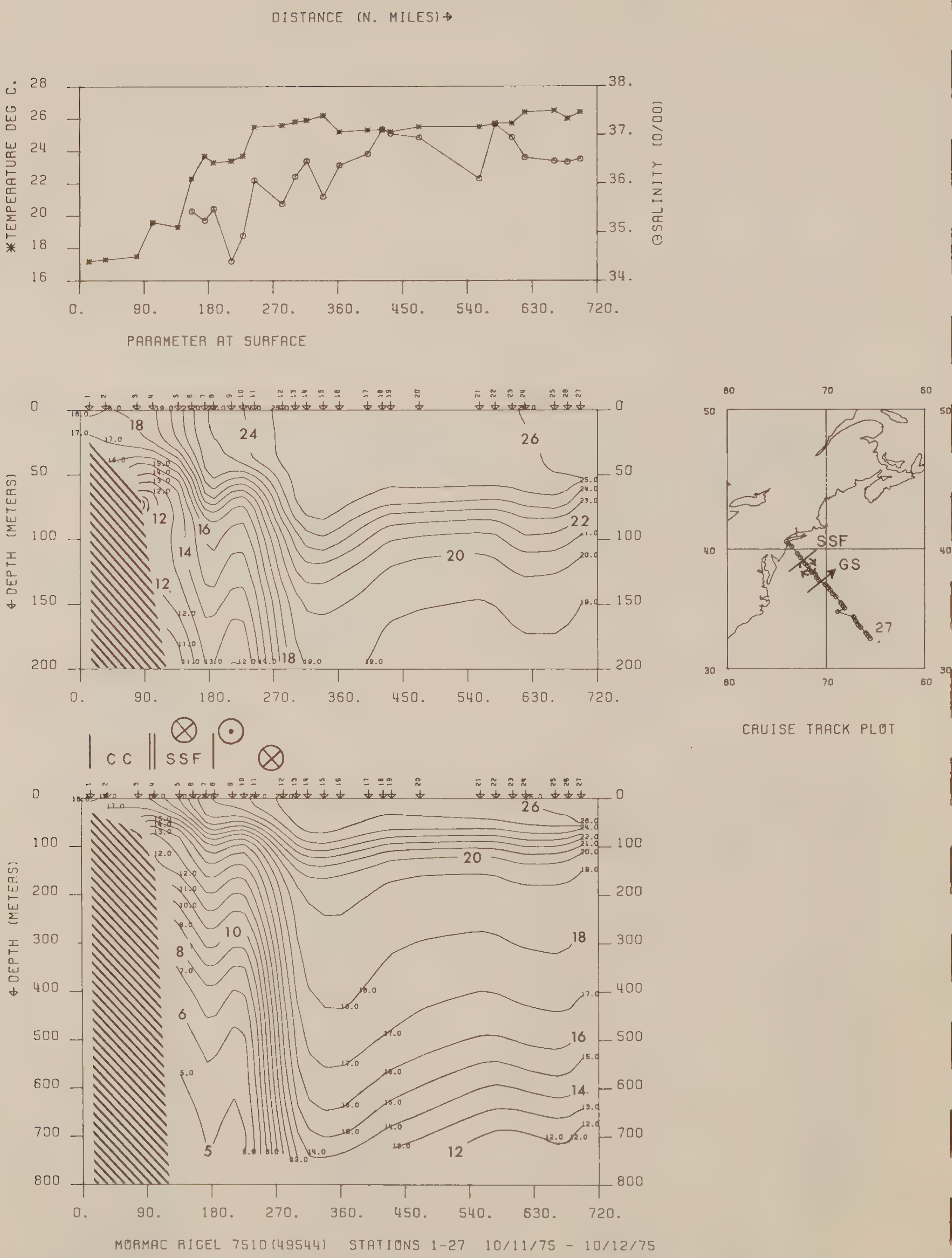


CRUISE TRACK PLOT

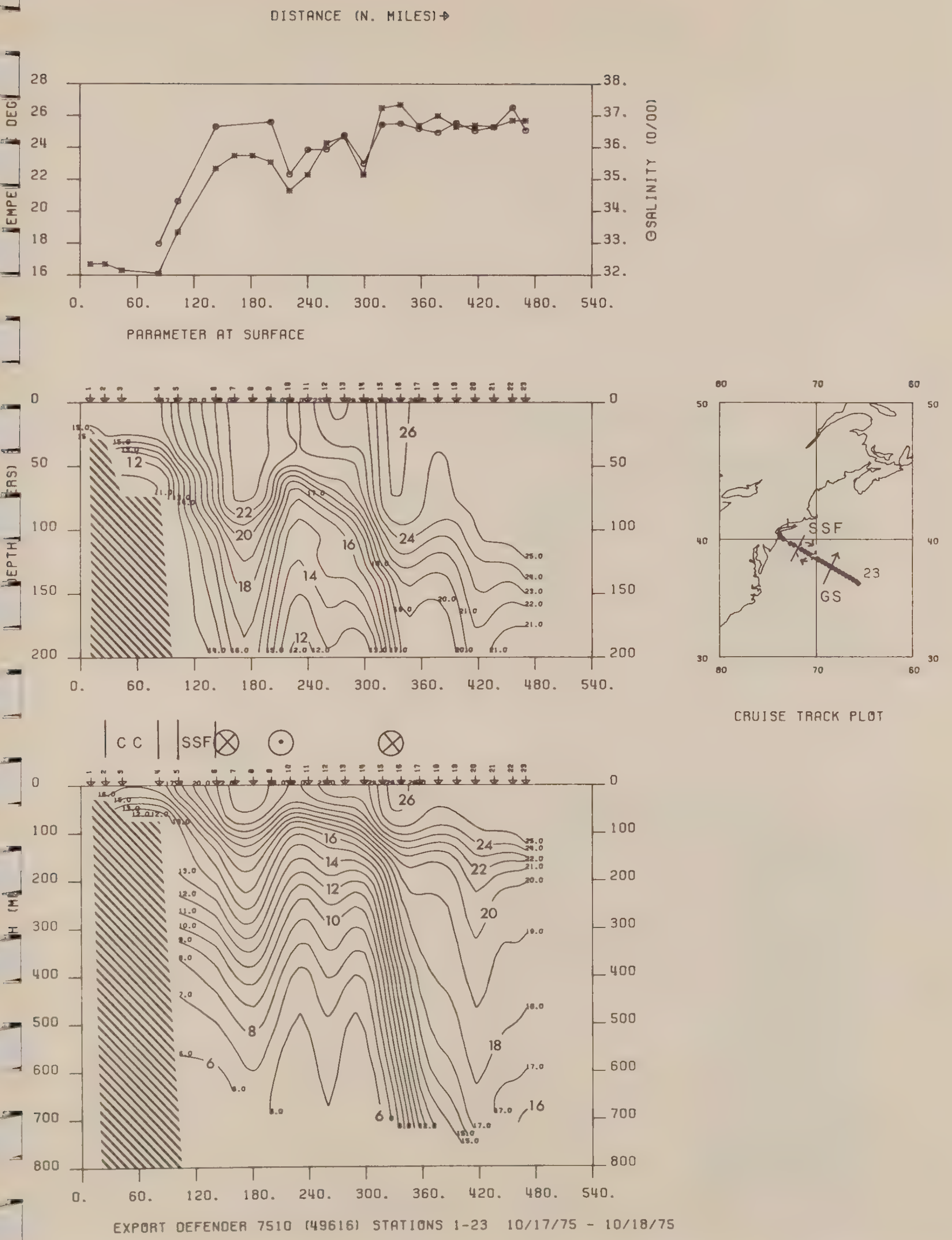
Appendix Figure 59.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Mormac Argo*—20-21 September 1975.



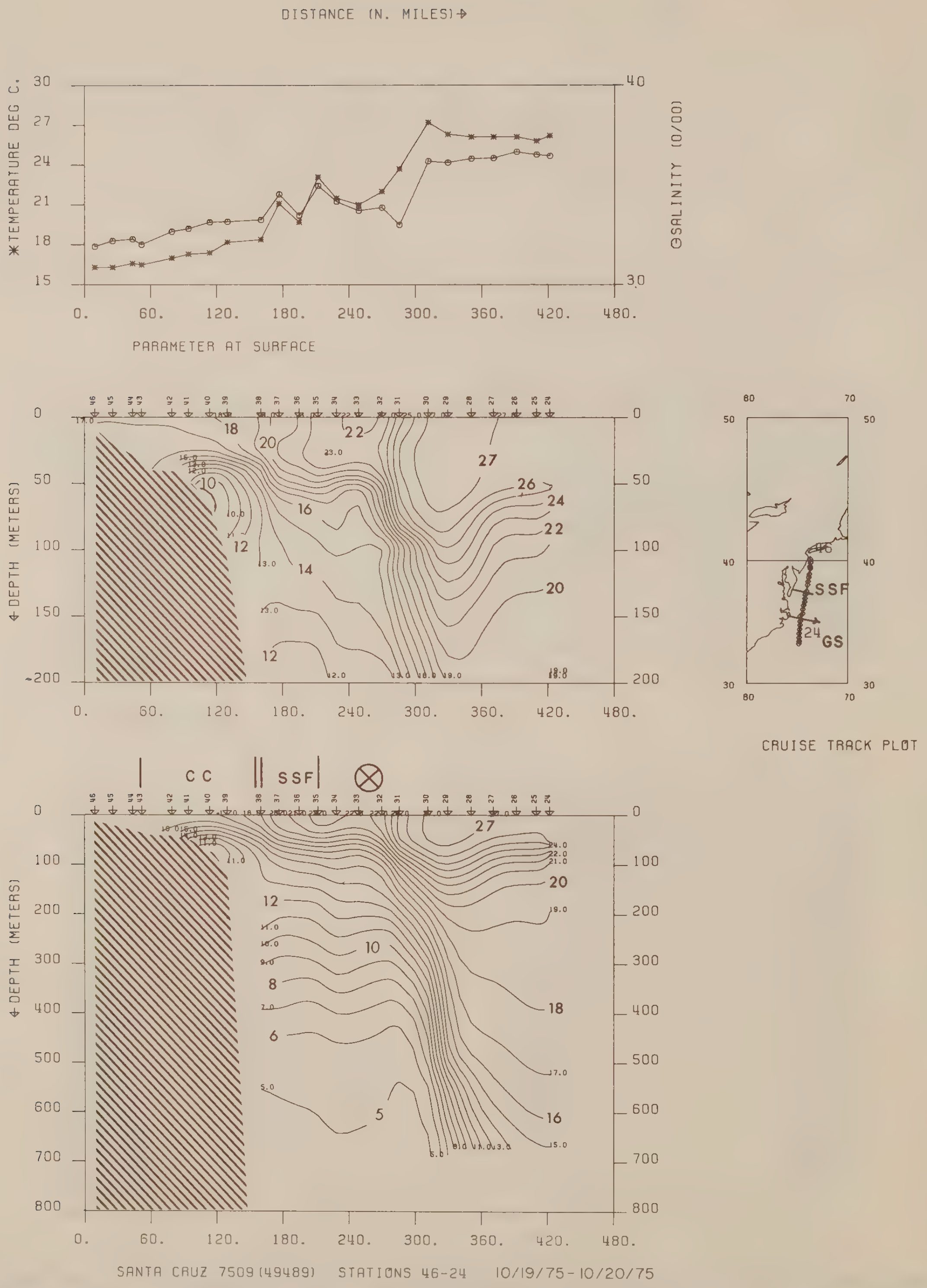
Appendix Figure 60.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Export Defender*—1-2 October 1975.



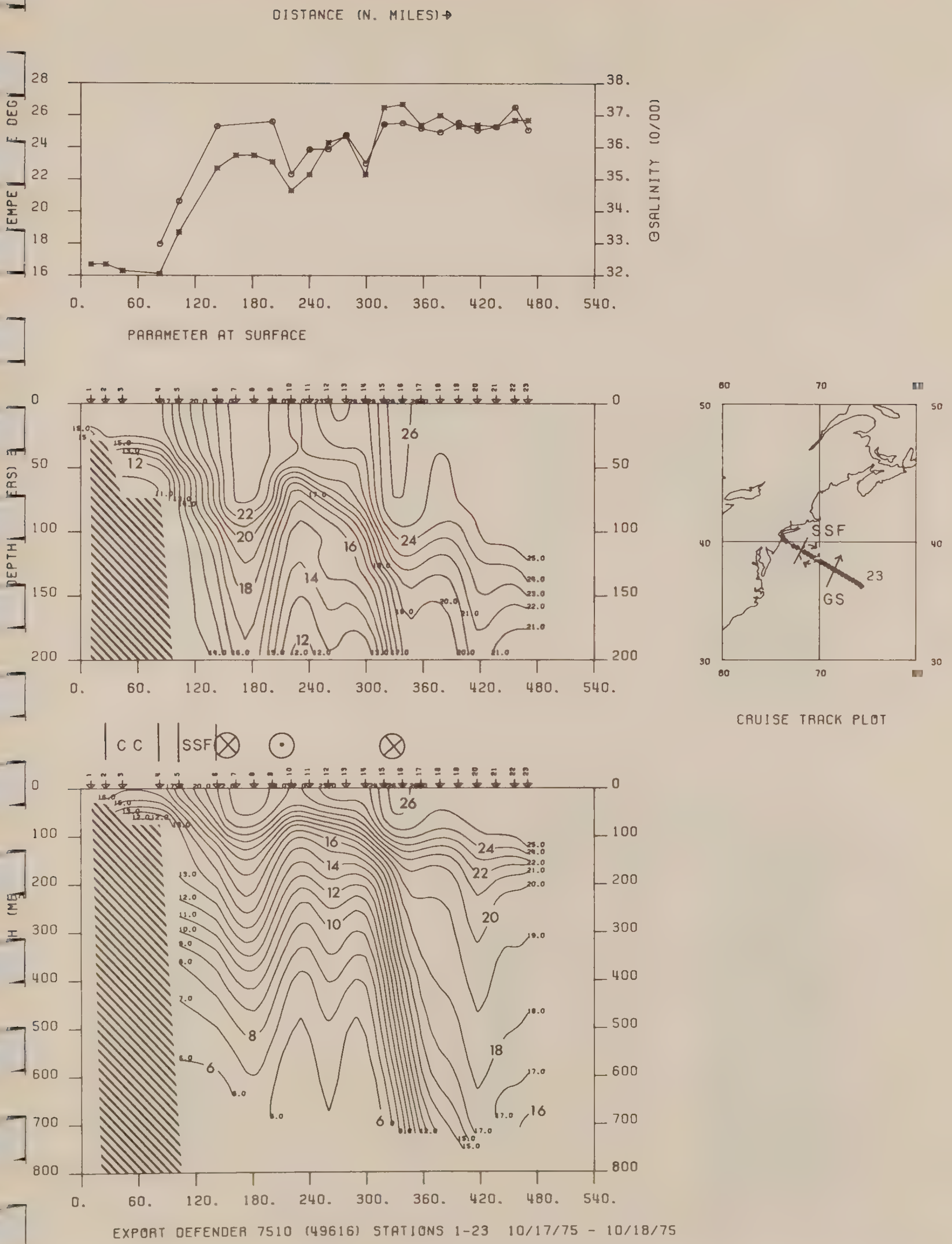
Appendix Figure 61.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Mormac Rigel*—11-12 October 1975.



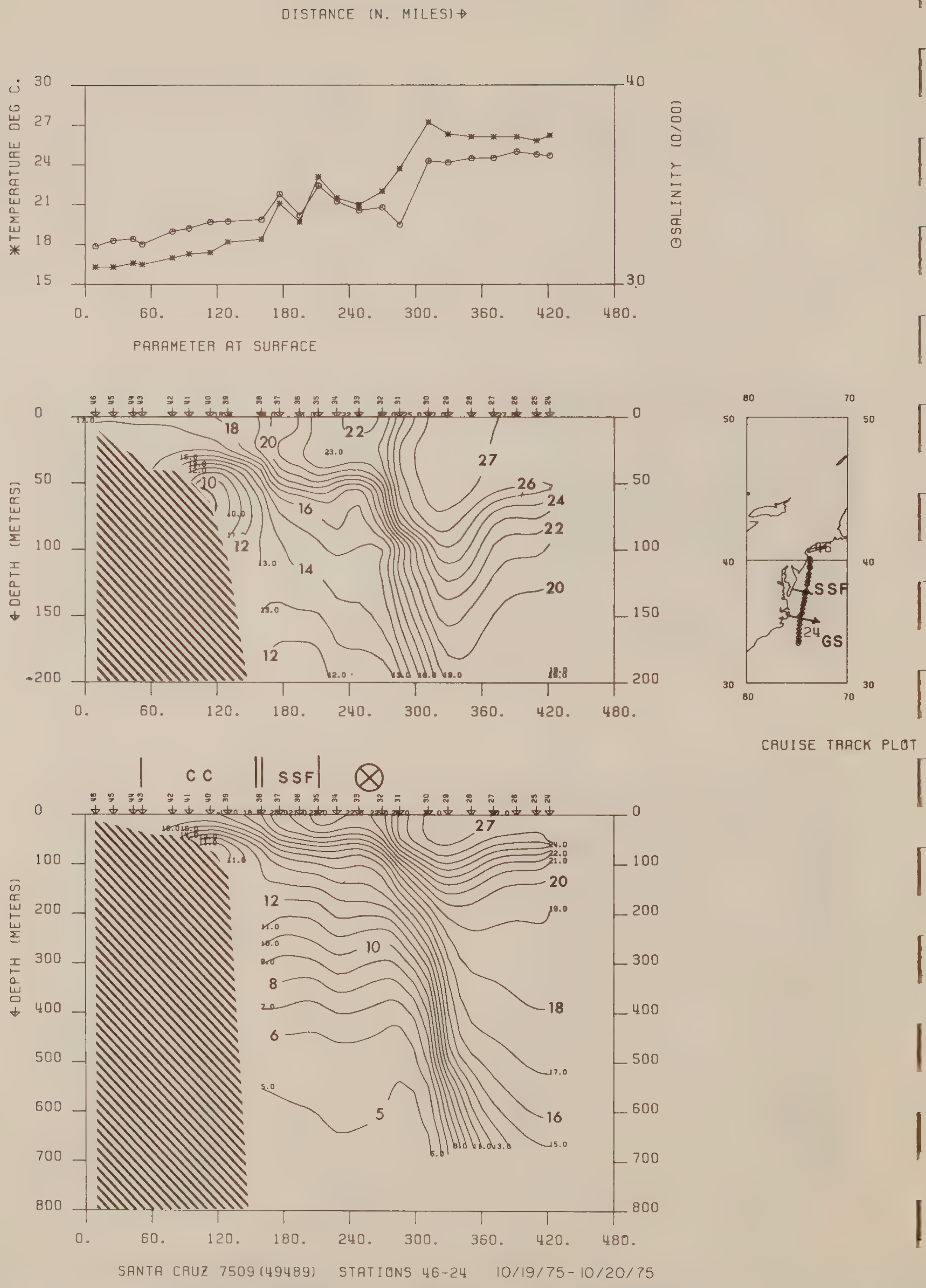
Appendix Figure 62.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Export Defender*—17-18 October 1975.



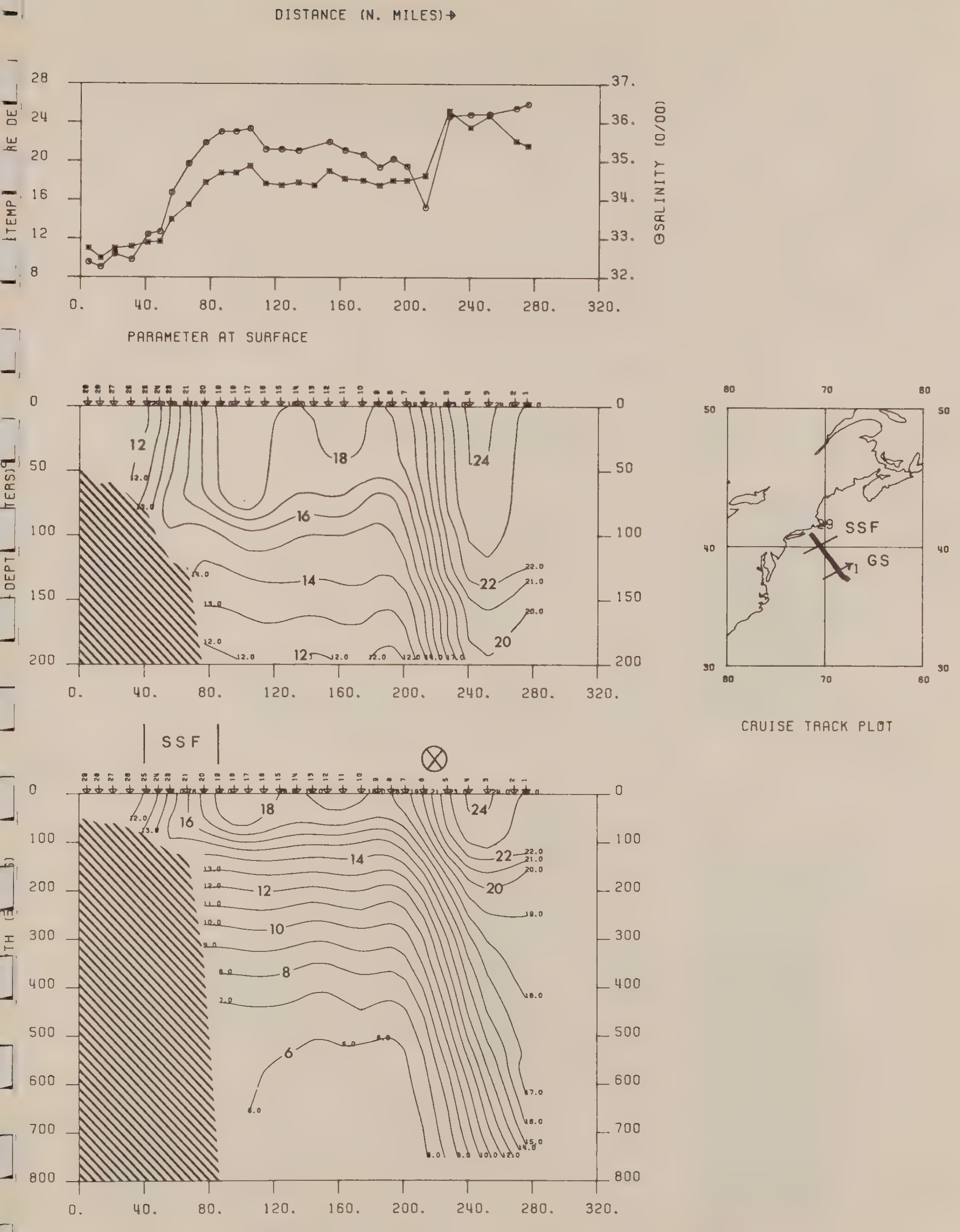
Appendix Figure 63.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Santa Cruz*—19-20 October 1975.



Appendix Figure 62.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Export Defender*—17-18 October 1975.



Appendix Figure 63.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Santa Cruz*—19-20 October 1975.



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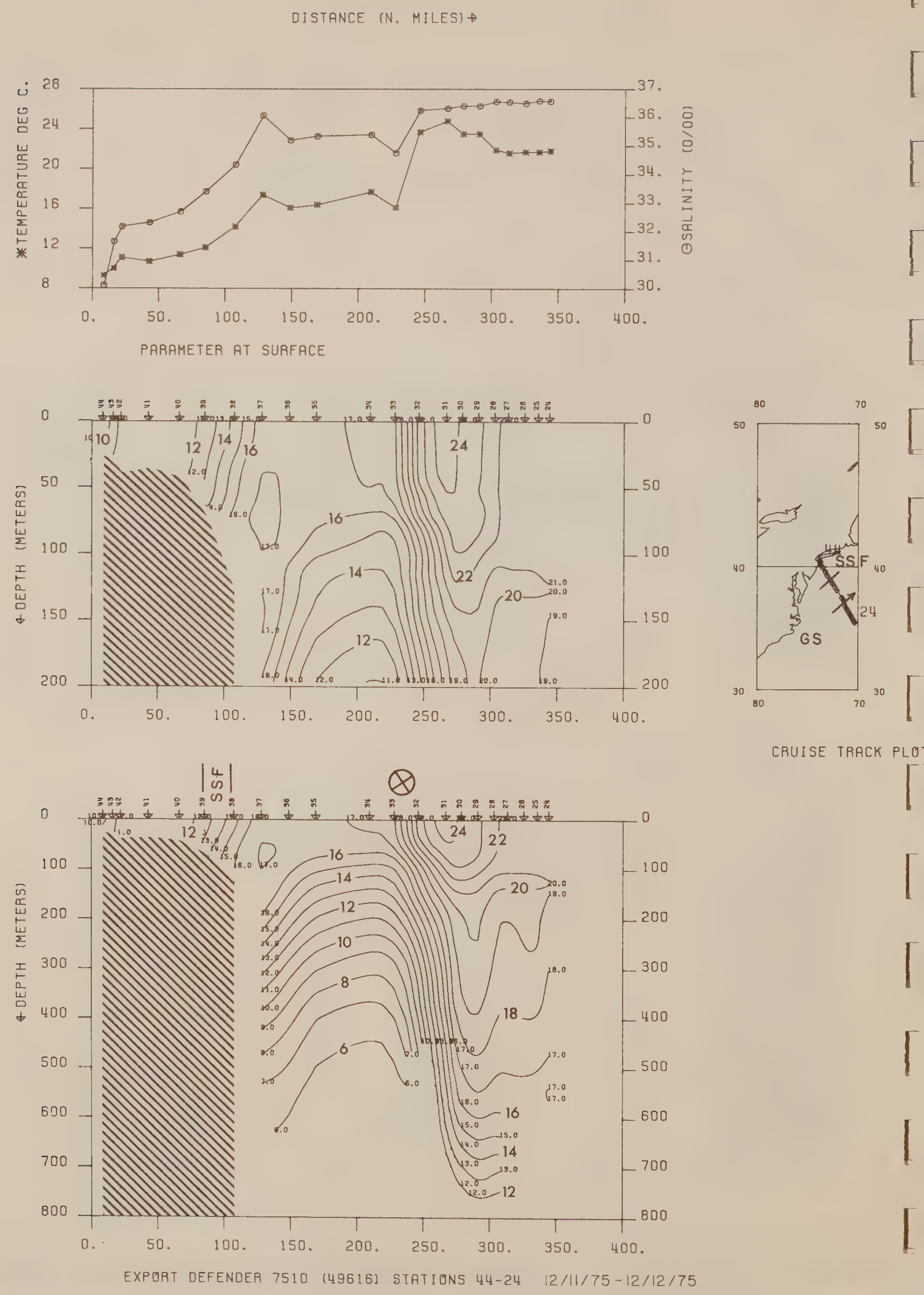
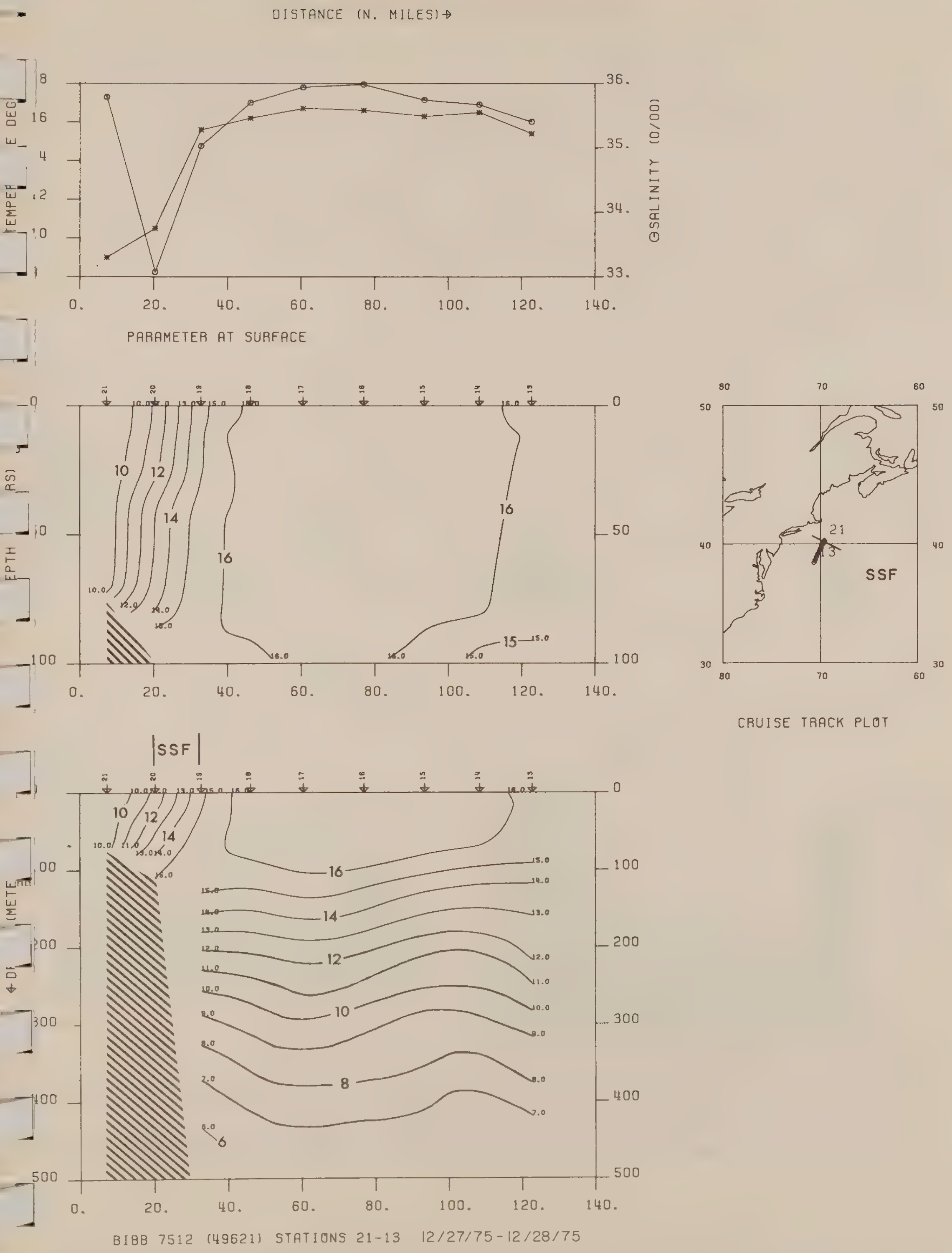
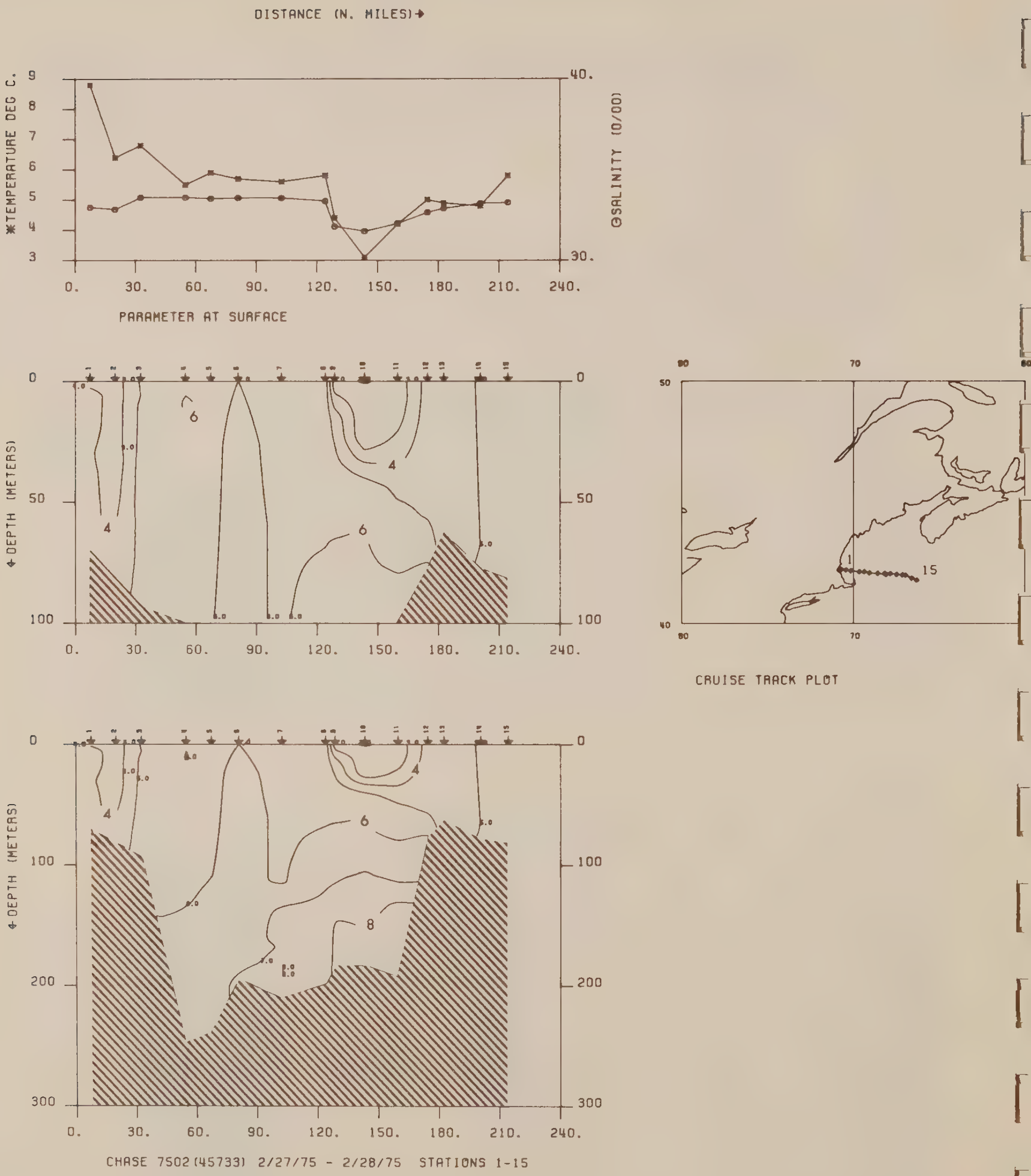
Appendix Figure 66.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 200 and 800 m. *Trident*—9-10 December 1975.



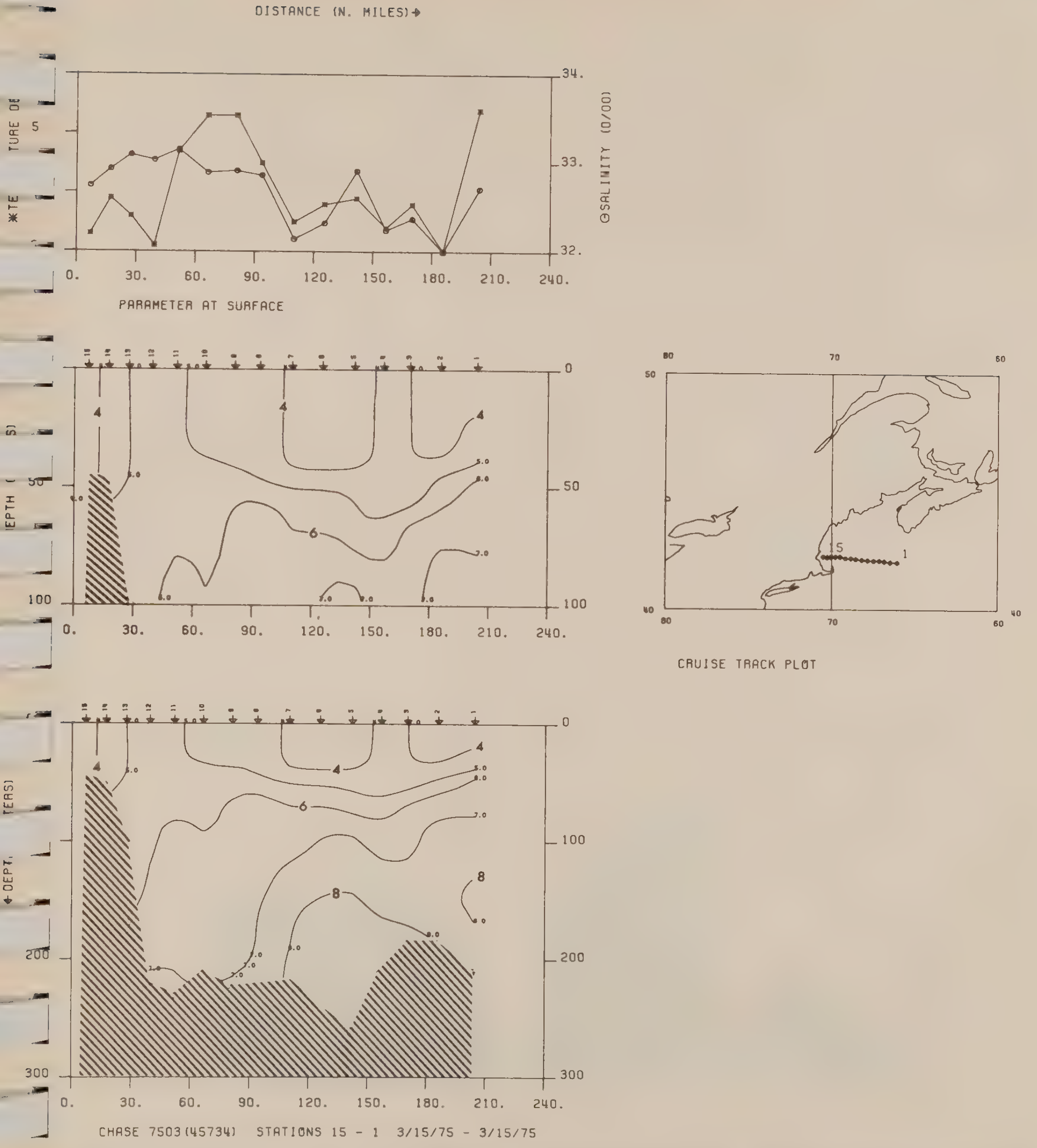
Appendix Figure 67.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and verti distribution of temperature (°C) in the upper 200 and 800 m. *Export Defender*—11-12 December 1975.



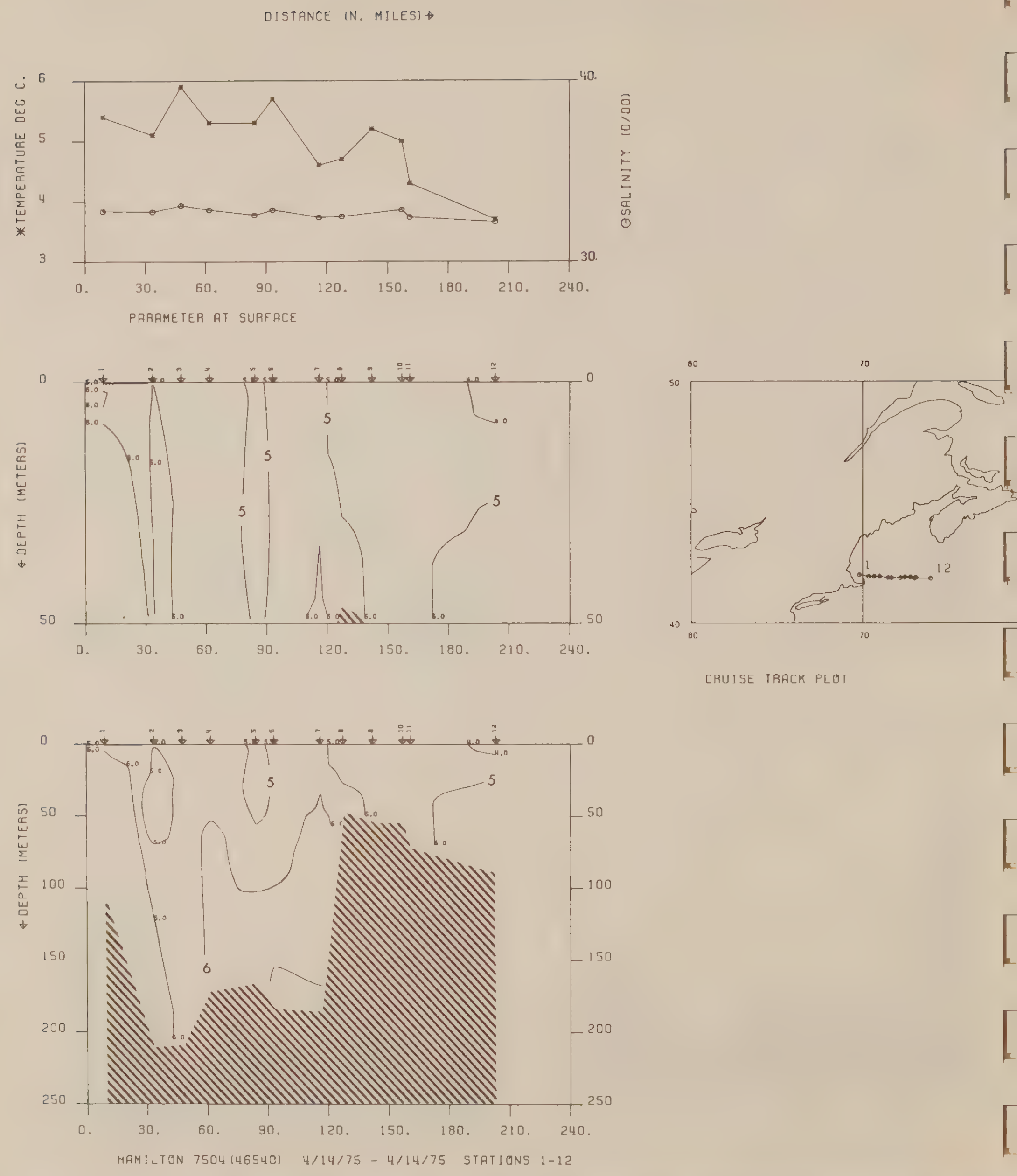
ndix Figure 68.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 100 and 500 m. *Bibb*—27-28 December 1975.



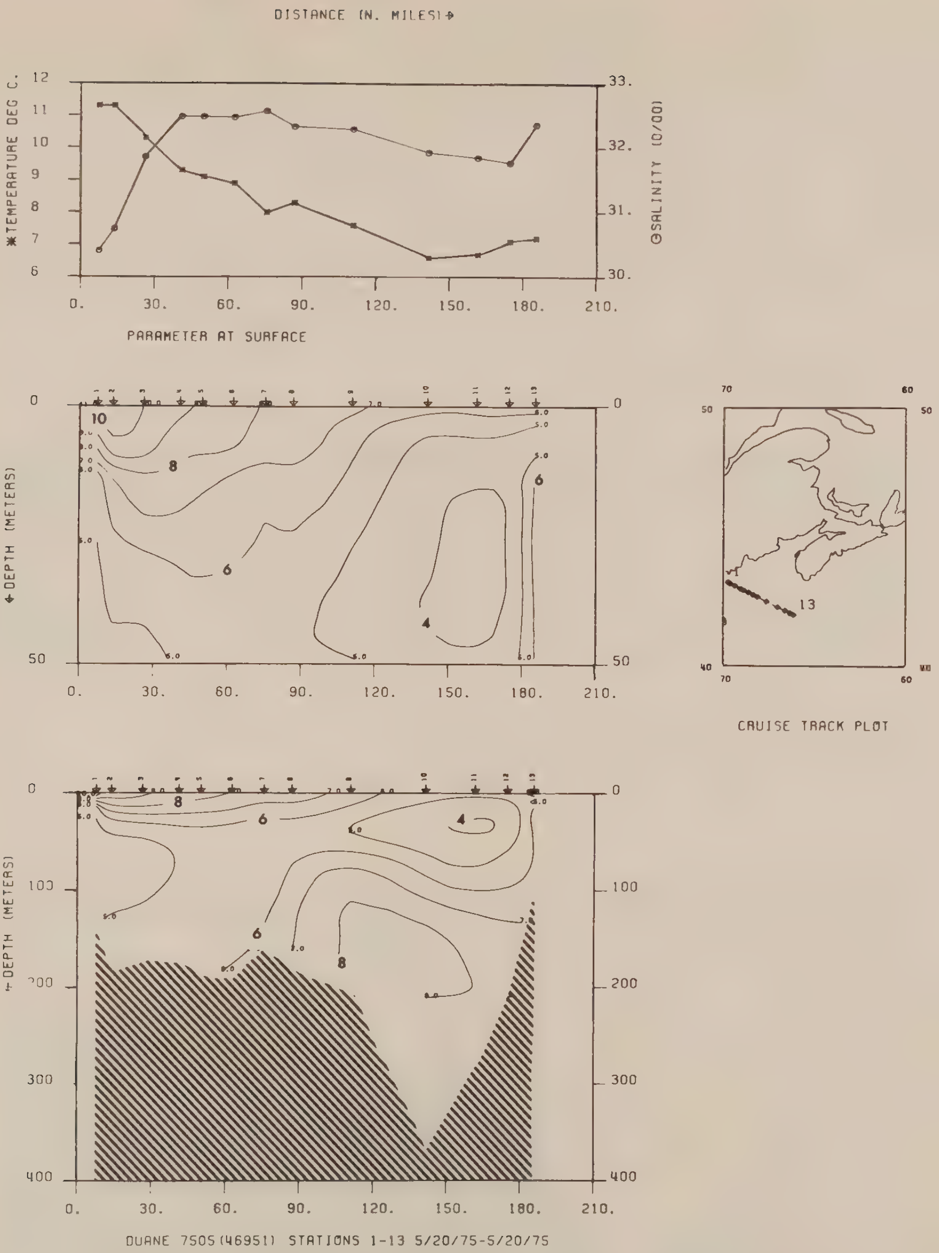
Appendix Figure 69.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distrib of temperature (°C) in the upper 100 and 300 m. *Chase*—27-28 February 1975.



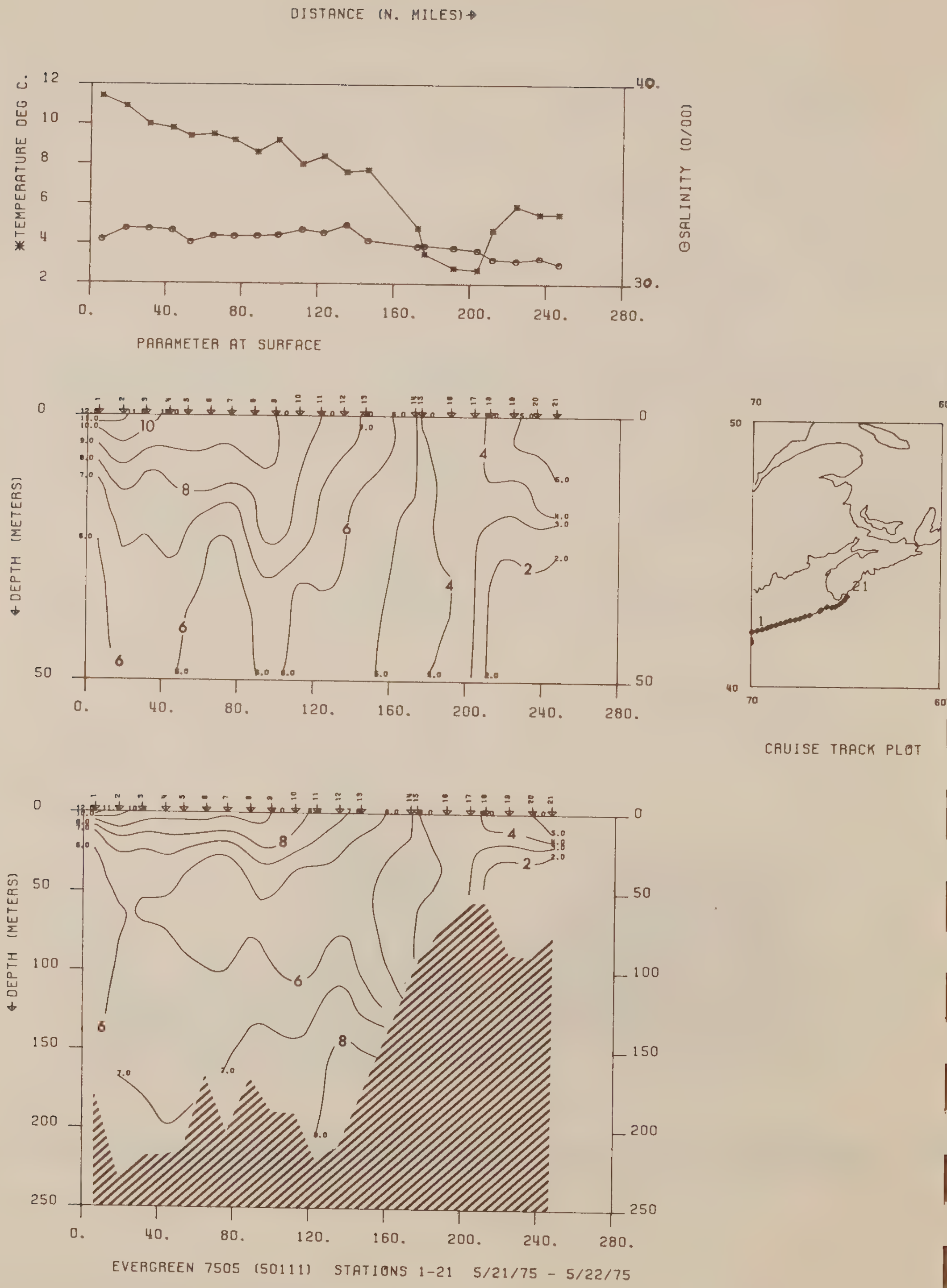
Appendix Figure 70.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 100 and 300 m. *Chase*—15 March 1975.



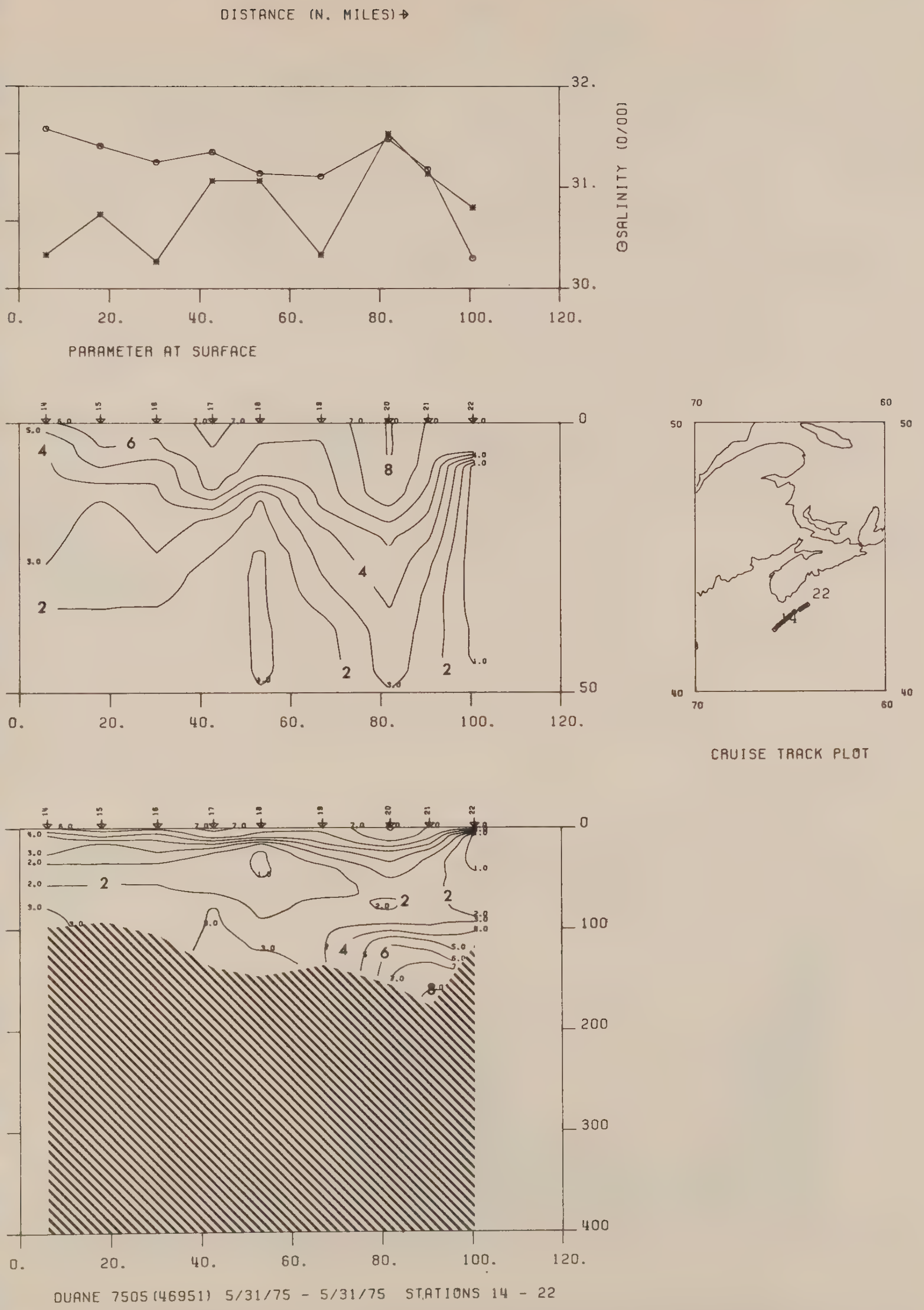
Appendix Figure 71.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distri of temperature (°C) in the upper 50 and 250 m. *Hamilton*—14 April 1975.



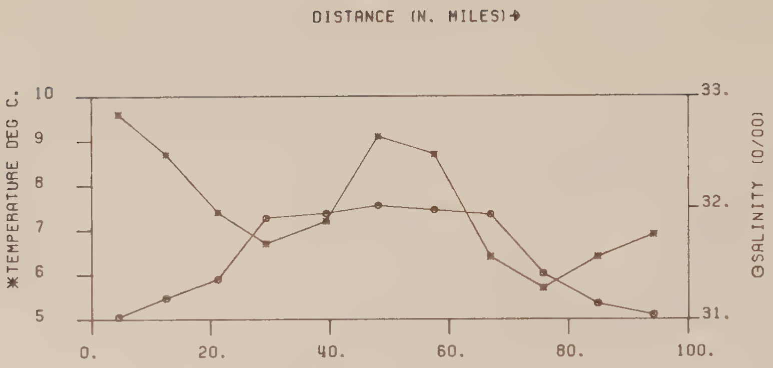
Appendix Figure 72.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 50 and 400 m. *Duane*—20 May 1975.



Appendix Figure 73.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 50 and 250 m. *Evergreen*—21-22 May 1975.



Appendix Figure 74.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 50 and 400 m. *Duane*—31 May 1975.



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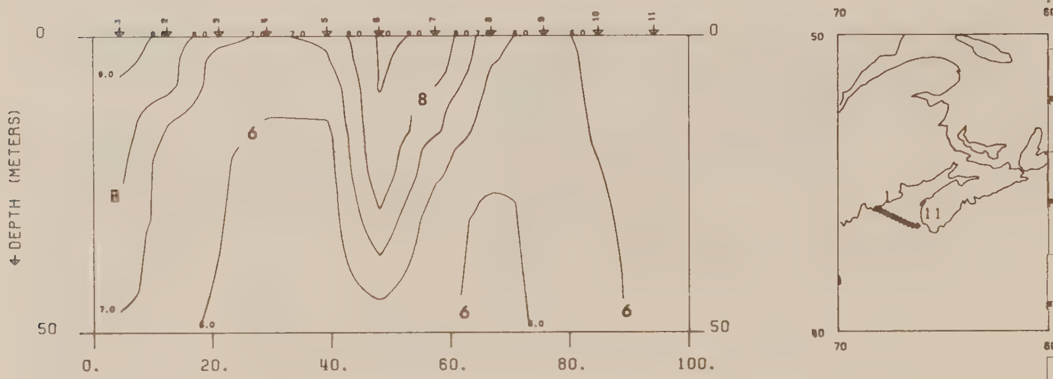
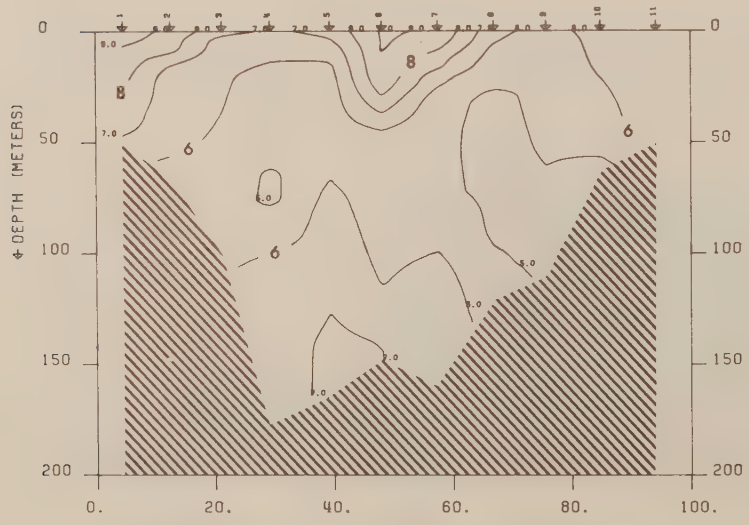


CRUISE TRACK PLOT



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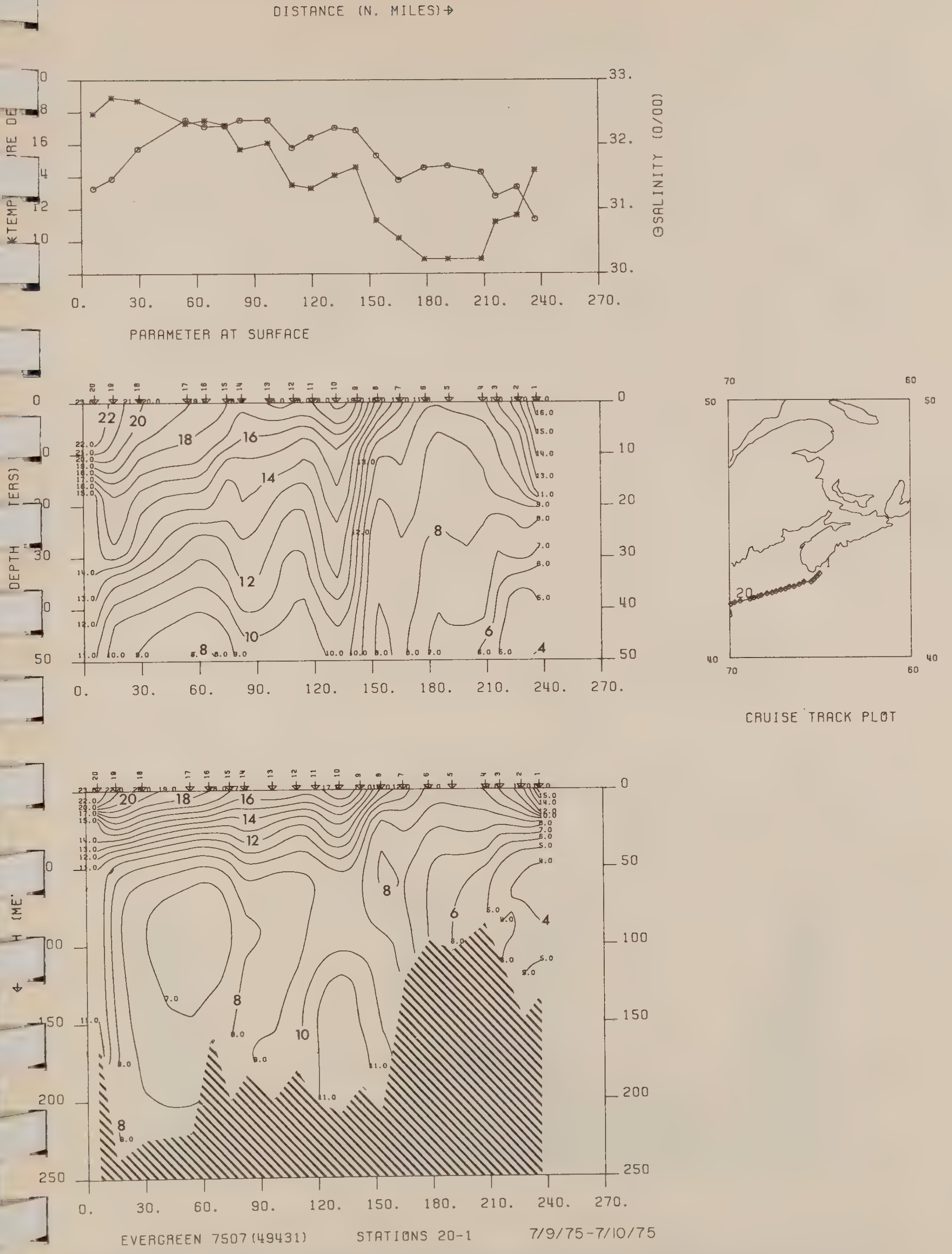
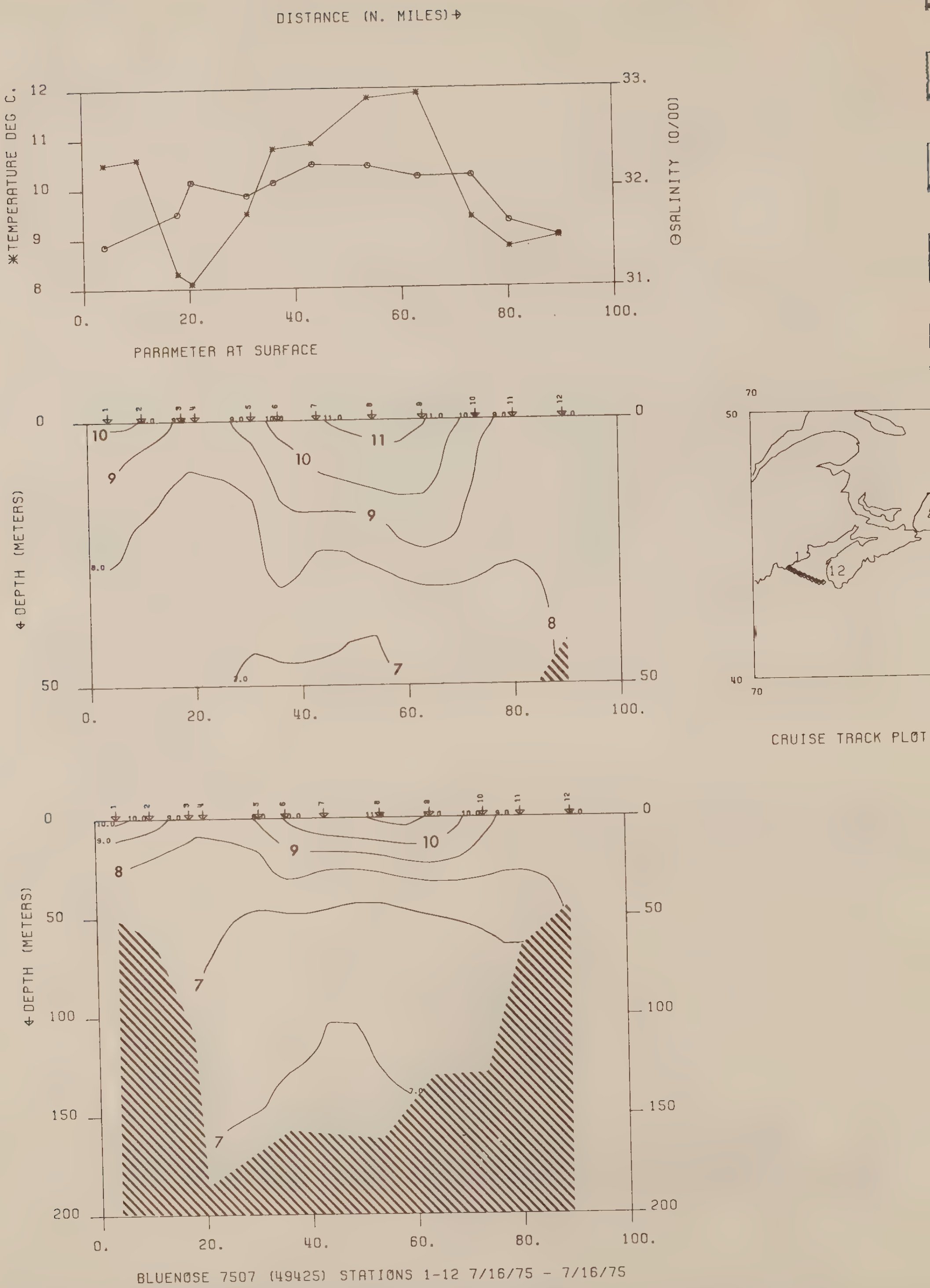
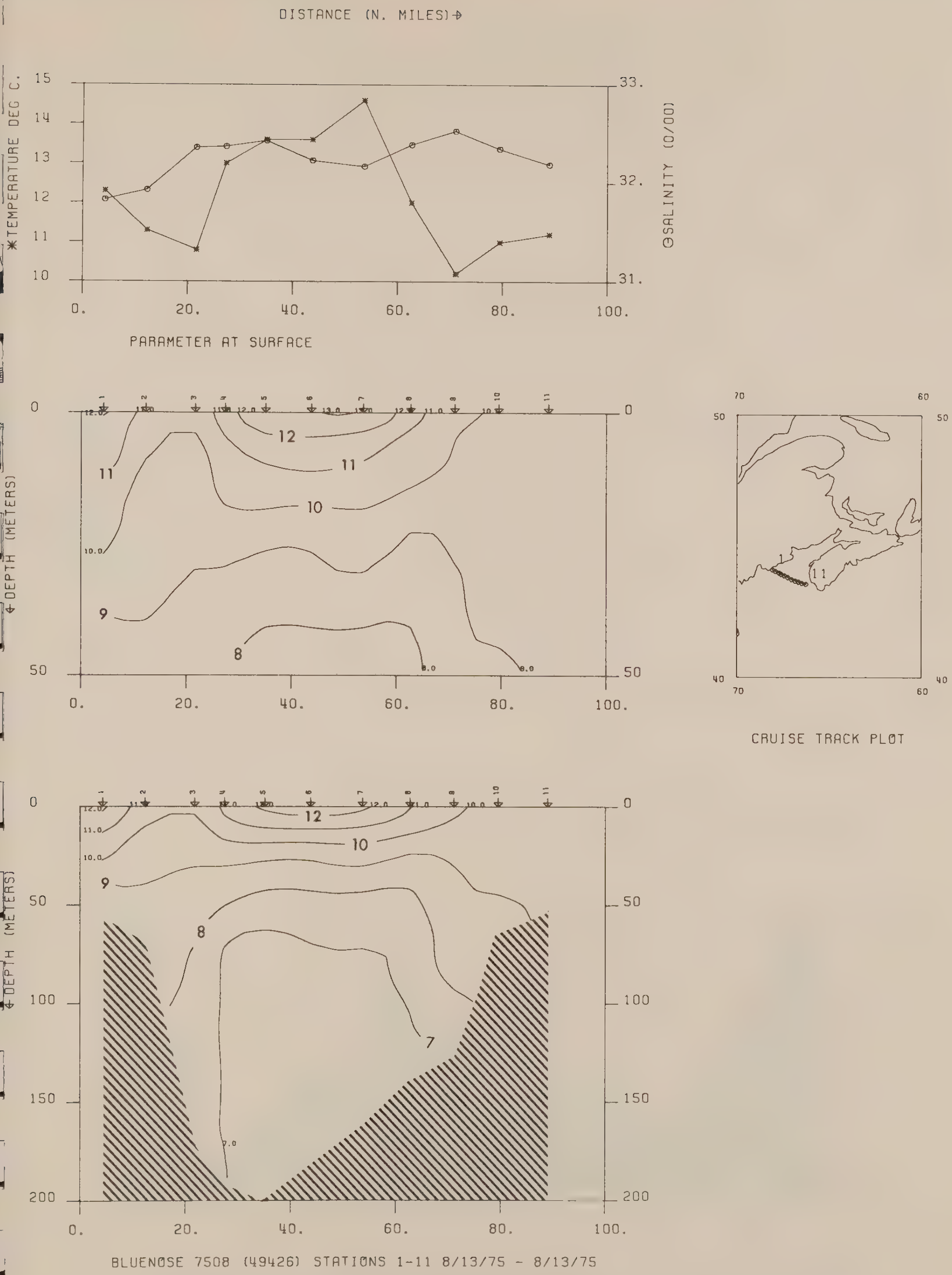
Appendix Figure 75.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and verti distribution of temperature (°C) in the upper 50 and 200 m. *Bluenose*—18 June 1975.



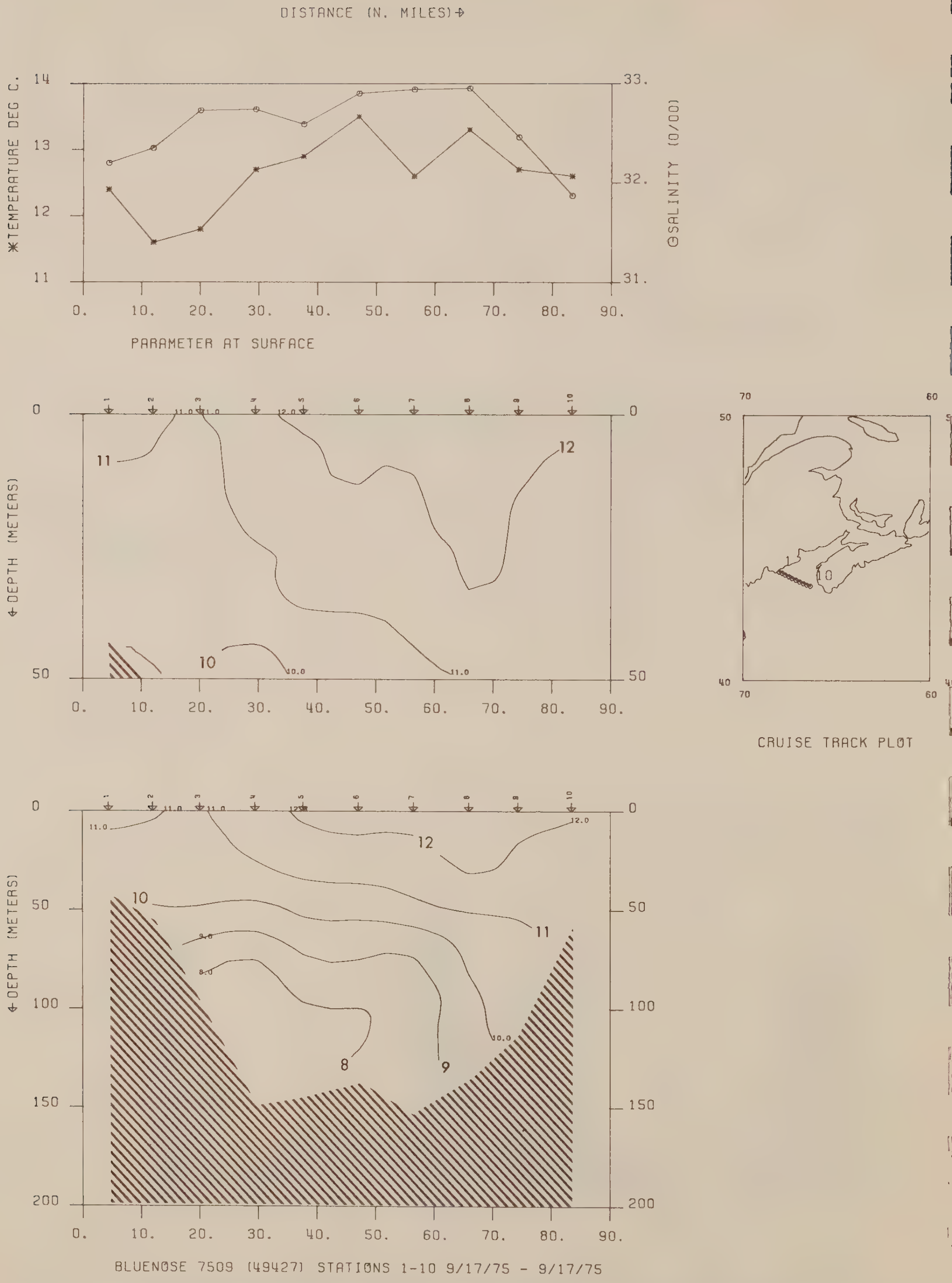
A endix Figure 76.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 50 and 250 m. *Evergreen*—9-10 July 1975.



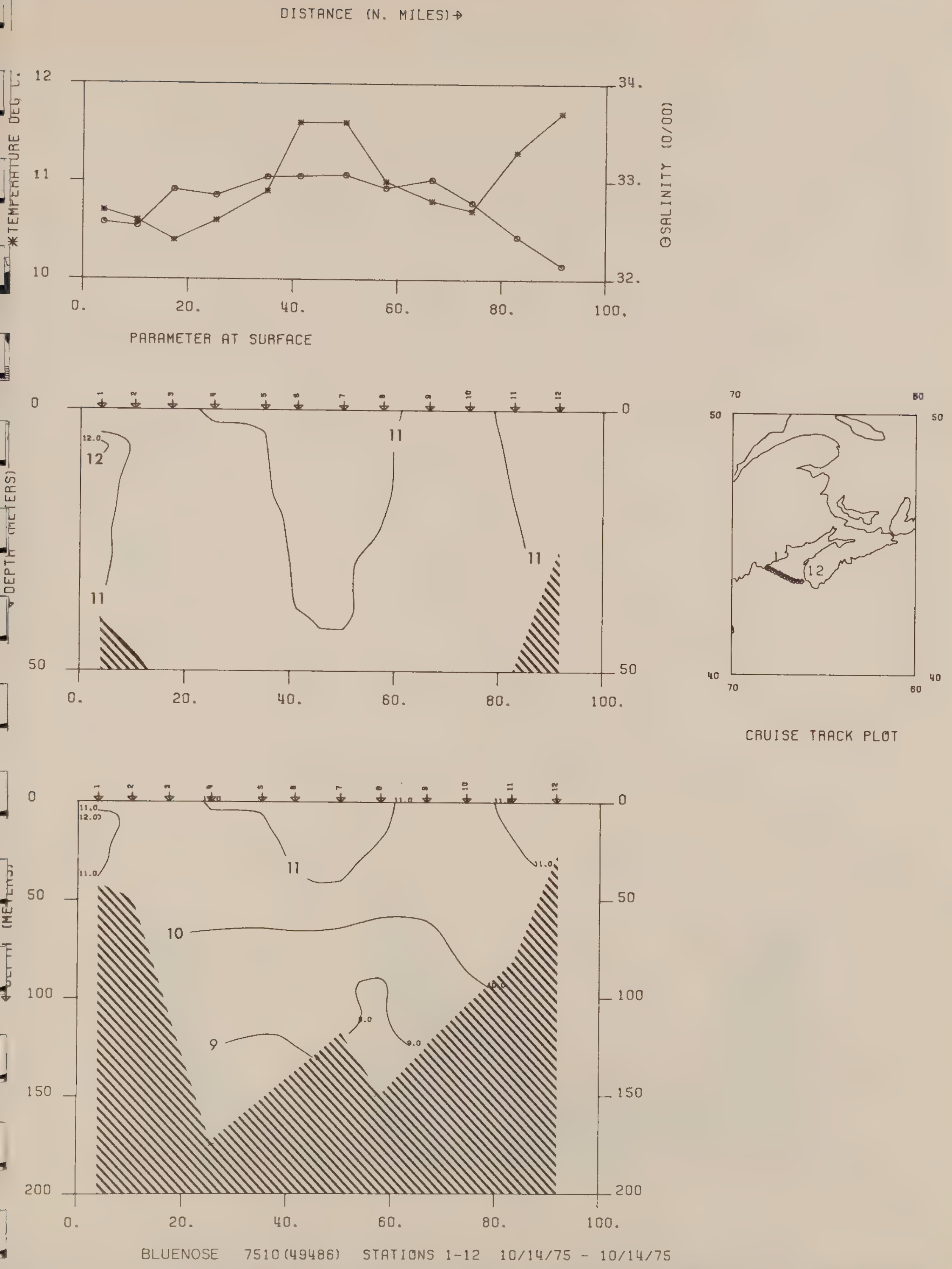
Appendix Figure 77.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and distribution of temperature (°C) in the upper 50 and 200 m. *Bluenose*—16 July 1975.



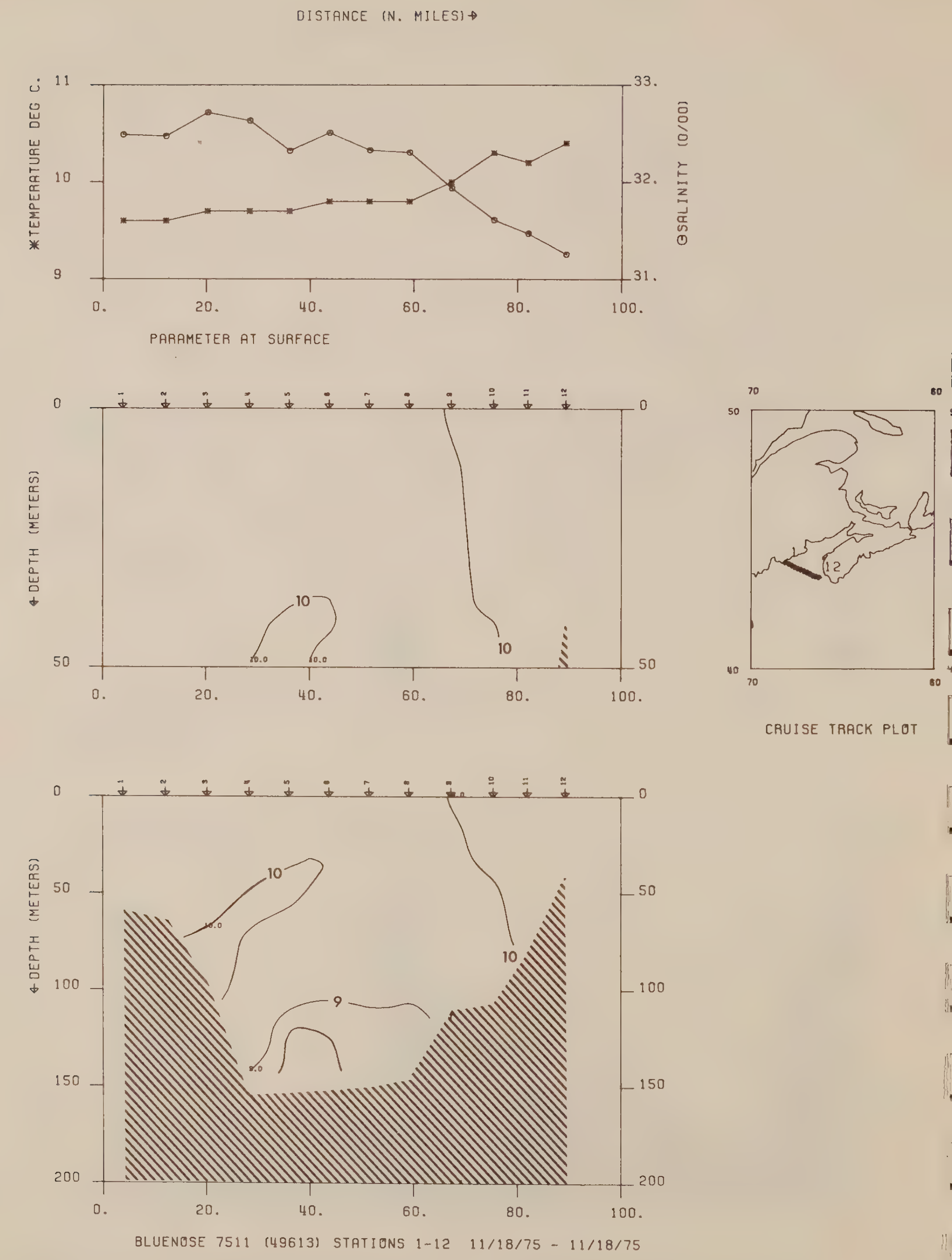
Appendix Figure 78.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 50 and 200 m. *Bluenose*—13 August 1975.



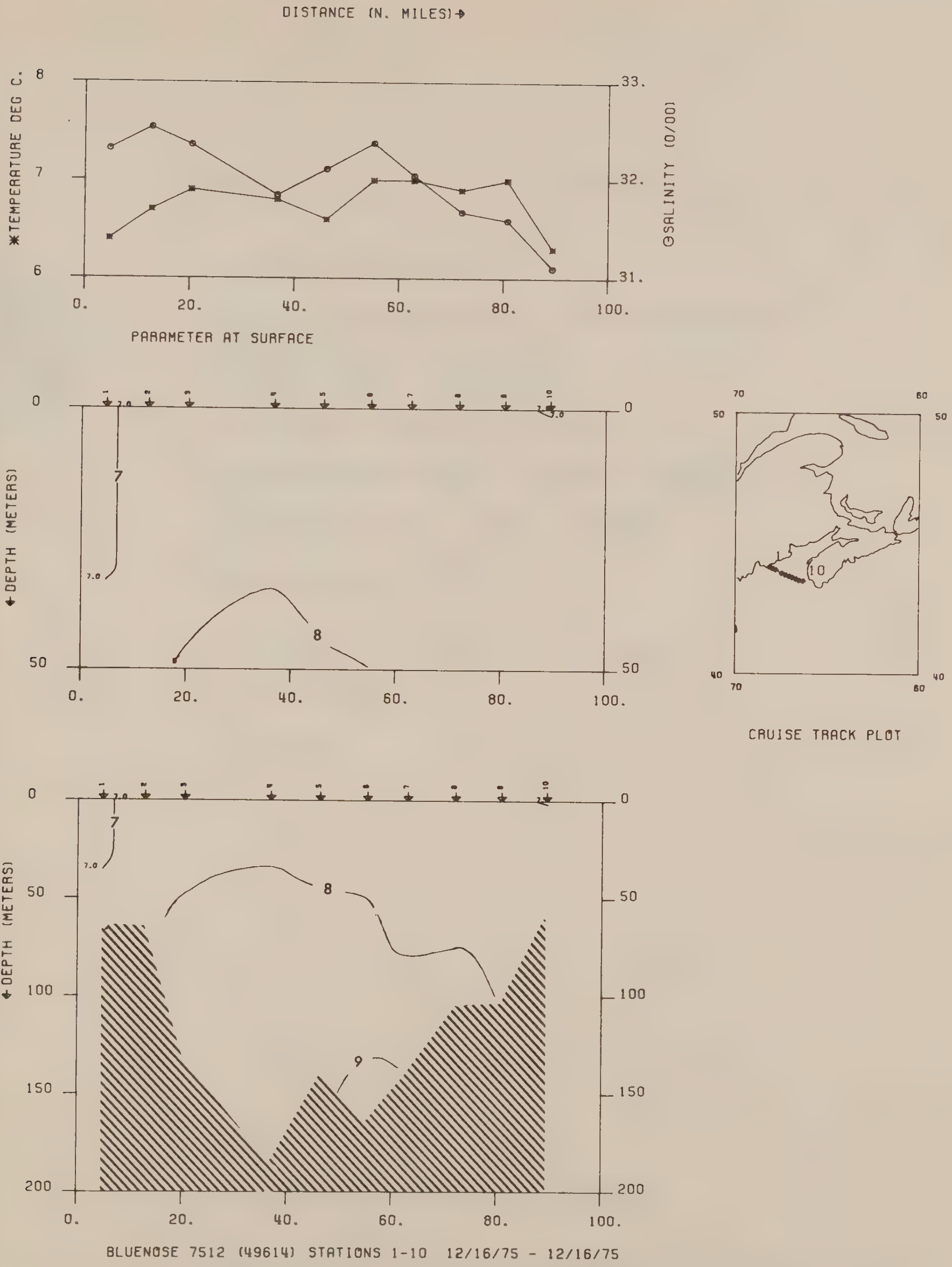
Appendix Figure 79.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertica distribution of temperature (°C) in the upper 50 and 200 m. *Bluenose*—17 September 1975.



ppendix Figure 80.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 50 and 200 m. *Bluenose*—14 October 1975.



Appendix Figure 81.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 50 and 200 m. *Bluenose*—18 November 1975.



Appendix Figure 82.—Horizontal distribution of sea surface temperature (°C) and sea surface salinity (‰) and vertical distribution of temperature (°C) in the upper 50 and 200 m. *Bluenose*—16 December 1975.

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NOAA Technical Report NMFS SSRF- 728

Vertical Sections of Semimonthly Mean Temperature on the San Francisco-Honolulu Route: From Expendable Bathythermograph Observations, June 1966-December 1974

J. F. T. Saur, L. E. Eber, D. R. McLain,
and C. E. Dorman

January 1979

U.S. DEPARTMENT OF COMMERCE
Juanita M. Kreps, Secretary
National Oceanic and Atmospheric Administration
Richard A. Frank, Administrator
Terry L. Leitzell, Assistant Administrator for Fisheries
National Marine Fisheries Service

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ical Sections of Semimonthly Mean Temperature on the San Francisco-Honolulu Route: From Expendable Bathythermograph Observations, June 1966-December 1974

J. F. T. SAUR,[1] L. E. EBER,[2] D. R. McLAIN,[3] and C. E. DORMAN[4]

ABSTRACT

Frequently repeated sections of expendable bathythermograph observations between San Francisco and Honolulu, taken by merchant vessels during the period June 1966 through December 1974, were analyzed to obtain mean seasonal cycles. Results are depicted in a set of semimonthly vertical sections of mean temperatures to 500 m and in a set of corresponding sections of 30-day mean temperature changes to 200 m. In addition, seasonal cycles at selected depths are included along with mean monthly vertical profiles for seven typical locations along the route.

The analyses reveal geographic and temporal facets of the mean thermal structure, including: 1) depth of the surface mixed layers in winter, 2) growth and decay of the seasonal thermocline, 3) decrease in depth of the permanent thermocline from Oahu to the California coast, 4) a region of temperature inversions or very weak vertical temperature gradients that develops between 50 and 100 m during the spring in the Transition Zone, and 5) the location and movement of warming and cooling regions during the year.

Vertical mixing appears to be the dominant process along most of the route for transmitting the annual surface warming and cooling cycle downwards to depths of 100 to 150 m. However, advective processes are active in the California Current.

Tables of semimonthly mean temperatures are given in an Appendix.

INTRODUCTION

ections of mean subsurface temperatures
face to 500 m, presented here, were derived
ne-series of sections of expendable bathy-
h (XBT) observations made from June 1966
ember 1974 by merchant ships between San
Calif., and Honolulu, Hawaii (Fig. 1). The
al program was developed by Saur and the
ed under the direction of the National
eries Service (NMFS). With technical as-
om the Fleet Numerical Weather Central
XBT systems were placed on merchant ships
tions were made routinely by the ship's
and Stevens (1972) described the XBT
servational procedures, and early projects for
bservations from cooperating ships.

of subsurface temperature observations on
cisco-Honolulu route began when the first
models of the XBT system became avail-
ork started as a 1- to 2-yr feasibility and development project on the use of the system aboard merchant vessels. It was then continued as an ocean monitoring project, and is now a part of a coordinated program among FNWC, NMFS, and NORPAX (North Pacific Experiment) programs to obtain XBT observations in the Pacific. The data are now routinely collected

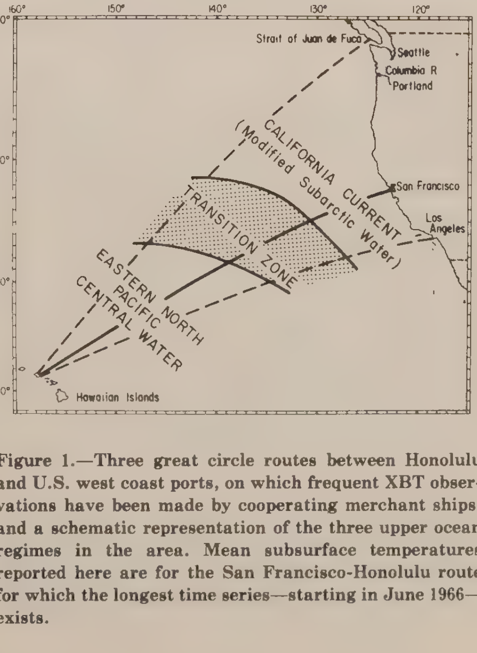


Figure 1.—Three great circle routes between Honolulu and U.S. west coast ports, on which frequent XBT observations have been made by cooperating merchant ships, and a schematic representation of the three upper ocean regimes in the area. Mean subsurface temperatures reported here are for the San Francisco-Honolulu route for which the longest time series—starting in June 1966—exists.

Fisheries Center La Jolla Laboratory, National Marine
ice, NOAA, La Jolla, Calif.; present address: Scripps In-
nography, La Jolla, CA 92093.

sheries Center La Jolla Laboratory, National Marine
, NOAA, La Jolla, CA 92038.

vironmental Group, National Marine Fisheries Service,
erey, CA 93940.

f Geological Sciences, San Diego State University, San
.

and selected vertical sections of the temperature distribution, with individual XBT profiles, have been published regularly in *Fishing Information*[5] since March 1972.

The ship routes between Honolulu and U.S. west coast ports cross the eastern limb of the major anticyclonic gyre of the North Pacific Ocean. If we confine our attention to the upper ocean, from the surface to a few hundred meters, we can identify three oceanic regimes: the California Current and the Eastern North Pacific Central waters separated by a Transition Zone (Fig. 1).

The waters in the California Current are mainly cooler, lower salinity waters of subarctic origin that are modified in their slow southeastward movement along the California coast. The Eastern North Pacific Central waters are warmer, higher salinity waters that occupy about the southwestern one-half of the route.

The Transition Zone is a complex region, not yet fully understood. In our region of interest it is bounded on the south and southwest by the subtropical front (Roden 1971, 1975). On the north and northeast it is bounded, respectively, by the subarctic front (Dodimead et al. 1963) and some type of southeastward extension of this feature, which LaFond and LaFond (1971) called the California Front. Saur (1974) described criteria for identifying these regimes from the XBT profiles, changes in slopes of isotherms in the vertical sections, and accompanying surface salinity observations. Laurs and Lynn (1977) discussed features of the Transition Zone from oceanographic observations made in June of several different years by fishery research vessels.

Mean temperatures presented here provide a base for study of temperature anomalies (Dorman and Saur 1977, 1978) and for further research on the relation of temperature variability to air-sea interaction and the changing environment of marine organisms.

METHODS

Observations

The time-distance distribution of XBT observations for the period June 1966 through December 1974 is shown in Fig. 2. The great circle distance from a reference point near Oahu was used for location. About 90% of the observations were made by ships on the great circle route. Some departures from the great circle track resulted from storms and the fact that tankers of Chevron Shipping Company generally followed a rhumb line (constant heading) course. For these observations taken at locations displaced from the usual route by 100 to 150 km, the use of great circle distance from Oahu tends to minimize temperature errors, because the general orientation of isotherms in the upper layers is northwest-southeast. The San Francisco end of our sectior
on the edge of the continental shelf a shor
south-southwest of the Farallon Islands and
(2,050 n.mi.) from the reference point.

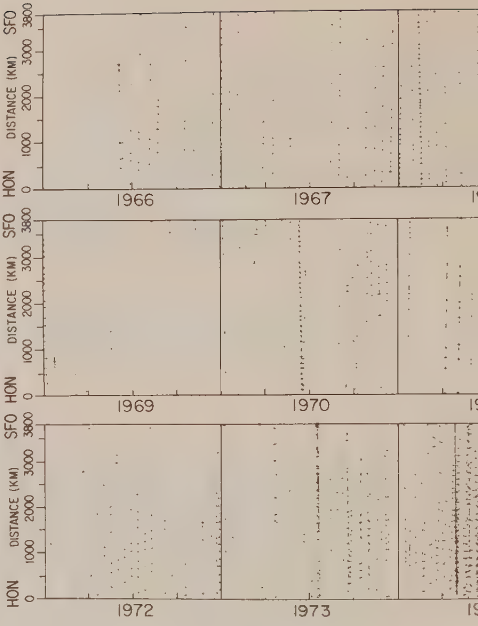


**Figure 2.—The time-distance distribution of XBT obser
near the San Francisco-Honolulu route from June 1
December 1974. Location of an observation is measurec
circle distance from an offshore reference point (lat. 2
157°42′W) near Honolulu.**

With the exception of the first year and one-
only four observations per day were scheduled
observations were taken on a 4-h schedule rela
ship's watch, rather than at prespecified "
Thus the location of observations along the ro
from one section to another. Also, the distanc
observations depended upon the ship's speed
ships cooperating in the program, normal sp
either about 16 to 17 kn or about 22 kn, so th
tance between observations was about 120 km
or 165 km (90 n.mi.), respectively. The slower s
generally get 27 to 30 observations per trans
faster ships about 17 to 20 observations. A fe
with more closely spaced observations for spec
were made when scientific personnel were ab

The frequency of sections reflects the g
change in character of the project. With the e
six sections made by oil tankers in the summ
all of the observations from the beginning of
in June 1966 through January 1971 were mad
vessel, *Californian,* a bulk-cargo and contain
Matson Navigation Company. This 17-kn sh
round trip about every 18 to 21 days, genera
observations on one 5-day leg only. During
several gaps of 4 to 8 wk duration occurred
ship repair schedules, short labor strikes,
ment failures.

---

[5] *Fishing Information* is a National Marine Fisheries Service monthly publication, containing fishery advisory information and environmental charts for the equatorial and North Pacific Ocean. It is compiled and distributed by the Southwest Fisheries Center, National Marine Fisheries Service, NOAA, P.O. Box 271, La Jolla, CA 92038.

prolonged maritime strike in 1971 interrupted the
s for two periods of nearly 3 and 5 mo each. A faster
n) ship, *Hawaiian Enterprise,* made most of the sec-
in 1971 and 1972, resulting in more frequent sec-
ns but with greater spacing between observations. As a
of the International Decade of Ocean Exploration
E) programs, we began instrumenting other ships in
1972 for other routes, but which also would make
ions irregularly on the San Francisco route. Using
ships, the frequency of sections on the San Fran-
route was increased in 1973 and intense coverage
obtained in 1974.

or the entire period from June 1966 through
mber 1974 there was a total of 4,913 observations
le 1). A number of the sections did not have com-
e coverage, with the coverage generally being poorest
either end of the route. This should be considered
interpreting the computer analyses which will be
nted.

rumentation

he basic sensing and recording system used through-
the period was the Sippican XBT system. Progres-
improvements were made in the recorder by the
facturer—some partially due to the field ex-
ences from this project—during the first few years,
-68. Since then, the recorder, with pressure sensitive
and an option switch for 460 m (1,500 ft) or 760 m
(2,500 ft) depth recording, has remained essentially unchanged.

The XBT system initially installed aboard the *Californian* included an experimental digitizer (developed by FNWC) with analog signal input from a retransmitting slidewire in the XBT recorder and digital output onto a 5-level punched paper tape at depth intervals of slightly less than 3 m (Saur and Stewart 1967). This was a dual purpose output for testing radio transmission of data to FNWC and for subsequent computer conversion, ashore, onto magnetic tape for permanent archives. The digitizer system became unstable after April 1969 which made the output unsuitable for archiving data. Although commercial digitizing systems were tried with some of the new recorders installed on other ships in 1971 and 1972, all of the data used herein from May 1969 onward were derived from the analog traces.

Sippican model T-4 XBT probes (460 m) were used during the first 1.5 yr of the project. We switched to use of model T-7 probes (760 m) in November 1967, to try to minimize probe-to-probe temperature errors by correcting deep temperatures to a smoothed deep level temperature (e.g., 600 or 700 m). This plan proved to be unworkable because the deep level temperatures could be offset to warmer temperatures by insulation failures on the wire and such a bias could not always be recognized with certainty by examination of the analog traces or vertical sections. At a later date mesoscale eddies were discovered and appeared to have deep

Table 1.—Number of expendable bathythermograph (XBT) sections by cooperating ship and total observations by year on the San Francisco-Honolulu route.

	Year									Total
	1966	1967	1968	1969	1970	1971	1972	1973	1974	sections
Matson Navigation Co.										
Californian	10	15	18	15	15	5			6	84
Hawaiian Enterprise						4	[1]18	19	[2]26	67
Hawaiian Citizen									1	1
Hawaiian Queen									10	10
Chevron Shipping Co.										
Idaho Standard					3					3
Washington Standard					2					2
McGarragill					1					1
Chevron Californian							1	2	1	4
Chevron Mississippi							1	4		5
States Lines										
Michigan						1				1
Idaho						1				1
American President Line										
President Cleveland						1				1
Pacific Far East Line										
Monterey								2	1	3
Mariposa									9	9
U.S. Coast Guard										
USCGC *Midgett*								2		2
Total sections	10	15	18	15	21	12	20	29	54	194
Total observations	204	329	550	435	592	229	453	635	1,486	4,913

[1] 11-16 February 1968 section had two XBT drops at each 4-h interval.

[2] Includes one special section, 27 April-1 May 1974, with hourly observations by R. L. Bernstein and C. A. Collins.

temperature changes equal to or greater than temperature error of the probes manufactured in 1968 and later.

As the cost of probes rose in the early 1970's we returned to using T-4 probes. With the merchant ships the amount of wire on the probe was the limiting factor on depth of the XBT observation. We found that the manufacturer's safety margin of excess wire on the probe usually permitted a reliable determination of temperature to 500 m.

Initial Processing

The procedures for initial processing of the observations into digital form on magnetic tape evolved as the project developed.

As noted earlier, the XBT system used during 1966-69 aboard the *Californian* included an experimental digitizer with a punched paper tape output. Most of the observations through April 1969 were computer translated from this output, which was regularly calibrated with the manufacturer's test canister on the visit to the ships before and after each voyage. In cases of digitizer failure significant points were read by eye from the analog traces, as were all observations for May-December 1969. Some sets of observations from 1967 to 1968 were semiautomatically digitized by FNWC in the early stages of development of its XBT digitizing system for computer determination of temperature-depth inflection points.

When the NMFS Pacific Environmental Group (PEG) was established in Monterey, the 1970 and later observations were digitized on an analog-digital table, under the supervision of McLain and using the facilities and computers of FNWC. The digitizing procedures generally followed those used at FNWC, described by Dale and Stevens (1970), except as modified by McLain at PEG to handle the NMFS data separately from FNWC data, to digitize analogs from T-4 probes to 500 m, and to plot vertical sections.

Quality Control

Preliminary vertical sections of the distribution of temperature were constructed, at first by hand and later by computer, for quality control. Saur reviewed each data set for possible errors utilizing the preliminary sections, analog traces, and continuity from section to section. Locations of observations were plotted to help check positions and an independent check of time and distance between observations was made against the ship's speed. For observations through 1970, copies of marine weather logs on which positions of 6-h weather observations were logged independently of XBT logs were also used to correct time and position errors.

The data checks were made to eliminate large errors due to instrument failure not detected before digitizing. These were of several types: 1) erroneously high temperatures throughout a trace due to defective thermistors or insulation failure from the start, 2) insulation failure during the probe descent which would introduce bias toward higher temperatures in the remai
of an analog record, and 3) slippage of the fri
clutch on the chart drive, which occurred mainly in
years before we became more experienced with the
system. Corrections were made at a later time
temperature values were interpolated at 5-m inte
between the surface and 300 m and at 10-m inte
between 300 and 500 m depth, for the computer ana
of temperature fields.

Computational Procedures

The determination of the vertical sections of
subsurface temperature presented herein involved
steps: 1) Conversion of observed temperatures
each section to temperatures on a stan
grid; 2) computation of a seasonally varying mea
each grid point by least squares fit of 12-, 6-, and
harmonics; and 3) reconstruction of gri
temperature fields from the harmonics, spatial sm
ing, and contouring of vertical sections. The com
programs used for this were adaptations by Eber of
he prepared at SWFC to map environmental variab
marine weather observations for presentation in *Fi*
Information.

1. **Conversion to a standard grid.**—It was p
ously mentioned that observations were not taken a
same predetermined location from section to sec
The first step was to analyze observed values from
section to a standard rectangular grid, using a proce
from Eber's EDMAP[6] (Environmental Data Mani
tion, Analysis, and Plotting) program.

The grid was selected with a distance interval of
km (50 n.mi.) and a depth interval of 10 m. This res
in a grid of 42 by 51 points representing a vertical se
3,800 km (2,050 n.mi.) by 500 m. Distance and d
were converted to grid coordinate units for
temperature analysis.

The procedure scanned the data list and f
temperature values to the grid. Each observation
tributed to the values at its nearest grid points accor
to an inverse weighting scheme based on distance
the observation to each of the grid points. The weig
factor decreased to zero at one grid length. If no obs
tion was found within one grid length of a grid poi
was flagged as a "no data" point in that section.

The procedure can be viewed as a refinement of ce
ing the observational data within 185-km (100 n.mi
20-m blocks that have a 50% overlap between adja
(both vertically and horizontally) blocks. Howeve
there is more than one observation within a block, ea
weighted according to the distance to the center o
block and the number of grid points it will affect.

---

[6] Unpublished documentation of the EDMAP program is on file
Southwest Fisheries Center, National Marine Fisheries Service,
La Jolla, CA 92038.

e gives somewhat greater weight to an observa- ar a grid point than would a weighting of 1-R^2, is the distance in fractions of a grid length.) If nly one observation within a unit grid area and e no observations in any of the surrounding grid he observed value would be assigned to each of nearest grid points.

iddate of the observations in a given section was d to its corresponding grid field for later use in ning harmonic coefficients. Thus the maximum r for data at either end of the section would be) to 2.5 days.

st squares harmonic fit.—In order to establish mean seasonal cycle for each gridpoint, a least it was made for the harmonic function

$$= (A_o)_{i,\,j} + \sum_{n=1}^{3} (A_n \cos n\omega t + B_n \sin n\omega t)_{i,\,j}$$

= $2\pi/365$, t is the day of the year, and i and j are t indices. Robinson (1976) also used the first monics of the Fourier function for time smooth- onthly mean values of mechanical bathyther- data (to 400 ft) for the North Pacific Ocean. ur initial gridded fields were not distributed at ervals in time, the terms which normally disap- armonic analysis of evenly spaced data (due to nality) are not zero when applying the least fit. Seven simultaneous equations for least t were solved to determine the seven unknown to represent the mean temperature and the12-, 4-mo cycles.

oid overweighting certain years because of mpling frequency, a set of harmonic constants rmined for each of three time periods: June cember 1970, 1971-73, and 1974. The first period ted because of the consistency of the sampling d earlier. The year 1974 was analyzed separate- e of the unusually high-density sampling. The tions from 1971 and 1972 were considered as 1 yr ined with 1973.

nts from the three periods were weighted and d by Dorman to provide the mean constants tative of the 1966-74 period. Weights assigned to ds were as follows:

Period	*Weight*
ne 1966-December 1970	4.5
1971-1973	2.0
1974	1.0

ical sections of mean temperature and mean ture change.—Appendix 1 contains vertical f the mean temperature structure along the San Francisco route, to depths of 500 m, for 24 equally spaced times throughout a year. (For convenience of identification these are labeled as 01 January, mid-January, 01 February, etc., to mid-December.)

The data field for each of the 24 mean vertical sections was reconstructed from the harmonic functions at each grid point. Because the time smoothing by the least squares fit was independent from point to point, a spatial smoothing was applied to the grid field before contouring.

The spatial smoothing was done with one pass of a 5 × 5 point (370 km by 40 m) smoother in the EDMAP program. The smoother was a two-step numerical filter, after Shapiro (1970), which was mostly effective for reducing amplitudes of perturbations with wave lengths of less than about four grid lengths. Its response was zero at a wave length of two grid lengths, 0.45 at three grid lengths, and 0.75 at four grid lengths. The response was 0.96, or greater, at wave lengths of seven grid lengths or more.

The contouring part of the EDMAP program divided each grid square into 25 subsquares, whose corner values were determined by Bessel's central difference formula for double quadratic interpolation. The intersection of each contour with the boundary of a subsquare it transects was determined by linear interpolation. The isotherms were computer plotted and are reproduced herein, with drafting touch-up only for clarity of presentation. The isotherms were not changed subjectively.

The major changes in the seasonally varying mean temperature were found to occur in the upper 200 m of the water column. The figures of Appendix 1 also show the distribution of the "30-day" temperature changes for the upper 200 m. The changes were computed from the spatially smoothed data (described on page 7) and are centered on the date of the vertical section in the upper panel. Note that there is a 50% overlap between two consecutive temperature change charts.

4. **Tables of mean temperature.**—Mean temperature values, in °C, for selected depths and alternating grid points (intervals of 185 km) are presented in Appendix 2. The values are those reconstructed from the fitted harmonics for the given grid point (distance and depth) and extracted before the grid was spatially smoothed for contouring. The tables are identified as 01 January, mid-January, etc., to mid-December, as were the vertical sections of Appendix 1.

RESULTS

This section discusses some of the general features of the mean temperature distributions in Appendix 1. Further, we have selected seven locations, each of which has vertical temperature structure and cycles characteristic of a part of the route. For each of these, Figure 3a-g shows the seasonally varying mean temperature for eight depths from the surface to 500 m, and Figure 4a-g shows the mean monthly vertical profiles of temperature for the warming and cooling periods.

Annual Cycles

At the surface the annual period is predominant at all locations (Fig. 3a-g). The annual range was smallest (about 4°C) near Oahu, largest (about 7°C) in the Transition Zone, and again smaller near the California coast (about 5°C). From near Oahu to the California front, the cycles at 50 m diminished in amplitude and the summer maximum lagged that at the surface by 1 to 2 mo. At the low salinity core of the California Current (Fig. 3f) the summer maximum penetrated almost simultaneously from the surface to 200 m. In the inshore area, California Current (Fig. 3g), the temperature range at 50 m was small (about 1°C). Here the minimum and the maximum temperatures lagged those at the surface by about 4 mo, and appear to be related to the occurrence of upwelling and the subsurface countercurrent, respectively.

Mixed Layers and Thermoclines

The surface mixed layers reach their maximum depth in winter, mid-February through early April, Appendix 1. Depths of the mixed layers were generally at least 100 m, except they decreased to 75 m near California. They were deepest, about 150 m, in the central part of the section (2,000 to 2,200 km) in the neighborhood of the subtropical front.

We consider the permanent thermocline to be the region of the maximum vertical temperature gradient in winter (January through March); vertical sections of Appendix 1 and profiles of Figure 4. In the western half of the section it was deeper (200 to 250 m) and warmer (15° to 17°C) than in the California Current region where it lay at depths of 100 to 120 m and had tempe
to 13°C. The seasonal thermoclines are forn
ing in spring and summer (May through Se
are generally confined to the upper 50 to 10
vertically mixed in winter. In the Califo
region the seasonal thermocline merged wi
nent thermocline into a single feature, w
Transition Zone the two thermoclines were
the spring by temperature inversions (next
later by a near thermostad (vertically isoth
Figure 4d. The latter was particularly e
summer (July through August) sections b
slope of the 15°-19°C isotherms at depths f
m at distances of 2,000 to 3,000 km from Ho
Eastern North Pacific Central waters from
near 1,800 to 2,000 km along the route, a
vertical temperature gradient occurred
seasonal and permanent thermoclines.

Temperature Inversions

A characteristic feature found by Saur
individual profiles in the Transition Zone (
and 3,000 km from Honolulu) was the occur
plex vertical thermal structure, especially
months. The thermocline would often be i
isothermal layers and temperature inversi
in some profiles. These were attributed to
by horizontal mixing, of layers of cool, low-
with warmer, higher salinity water of nea
density. These features usually are relative
and transient, so that during our computat
they were generally smoothed out. Ho

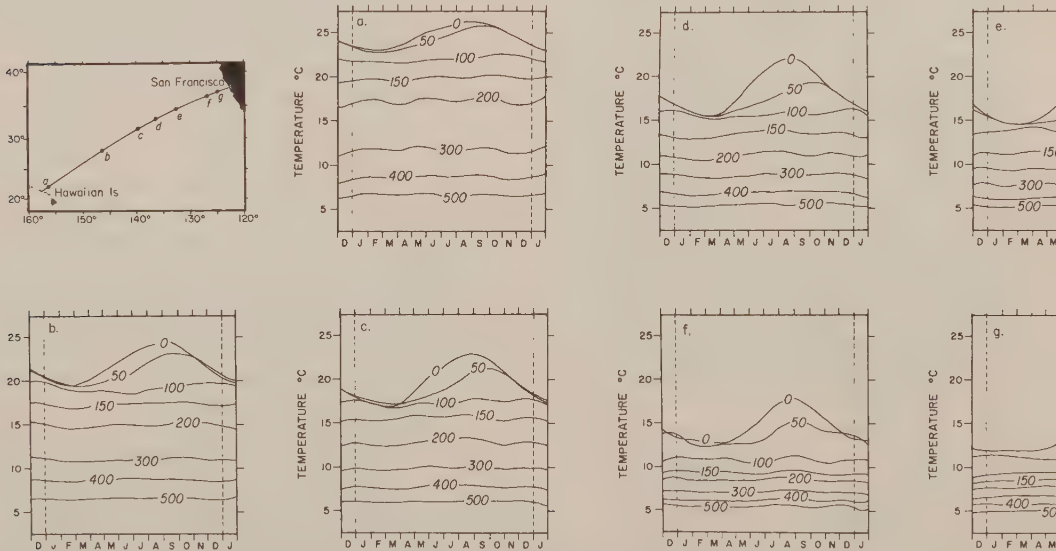
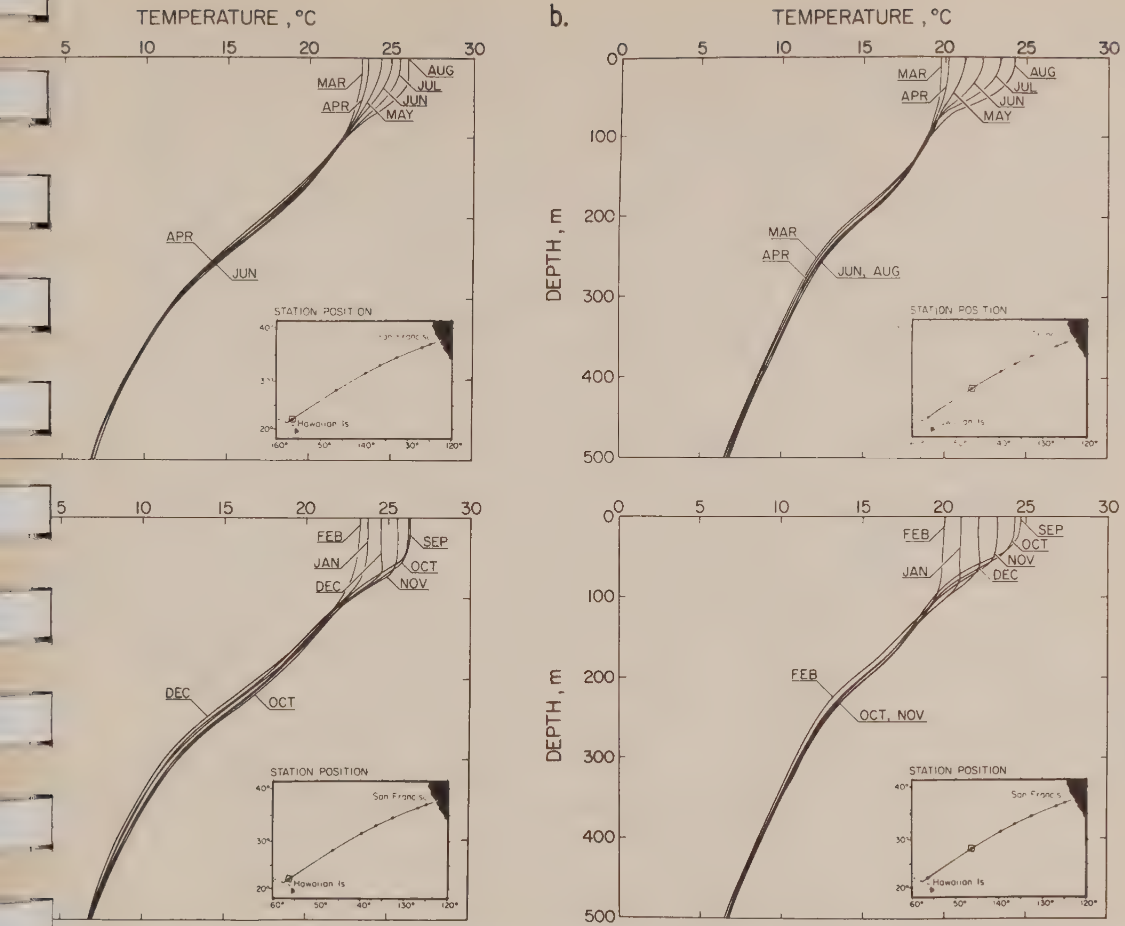


Figure 3.—Station position chart and mean temperature cycles at selected depths (meters) for seven typical locations, great
from offshore reference point (lat. 21°12′N, long. 157°42′W) near Honolulu, and geographic coordinates: a. Near Oahu: 185
lat. 22°10′N, long. 156°15′W. b. Eastern North Pacific Central Water: 1,390 km (750 n.mi.); lat. 28°17′N, long. 146°20′W. c. S
2,130 km (1,150 n.mi.); lat. 31°39′N, long. 139°42′W. d. Transition Zone: 2,500 km (1,350 n.mi); lat. 33°12′N, long. 136°12′W
front: 2,870 km (1,550 n.mi.); lat. 34°39′N, long. 132°35′W. f. Low salinity core, California Current: 3,430 km (1,850 n.mi.); l
126°55′W. g. Inshore region, California Current: 3,615 km (1,950 n.mi.); lat. 37°12′N, long. 124°59′W.



lonthly profiles of mean temperature (°C), for warming and cooling periods at seven typical locations (shown by diamond on inset nce from offshore reference point near Honolulu and geographic coordinates as in Figure 3. a. Near Oahu. b. Eastern North tral Water. c. Subtropical front. d. Transition Zone. e. California front. f. Low-salinity core of the California Current. of California Current.

versions remained in the vertical sections e.g., the 15°C isotherm in the 01 April sec- 15°-17°C isotherms in the mid-April section, 7°C isotherms in the 01 May section, and the in the mid-May section. It appears that, ge, when surface warming begins in the d vertical mixing is suppressed, the warmer, lini Eastern North Pacific Central waters the California coast around 100 m, under- ne low-salinity, modified subarctic waters still cool around 50 m.

nths, e.g., mid-January section of Appen- peared to be a temperature maximum at of the mixed layer between 1,200 and 3,000 km section. From an examination of individual found that these were not typical of usual re was almost always an isothermal layer of the thermocline. The apparent maximum om the tendency of the three harmonics to give mperatures for this area in winter which were slightly low, 0.1° to 0.2°C. The weak horizontal temperature gradients and vertical exaggeration of the section, amplified the effect in the computer contoured sections.

Structure Below the Permanent Thermocline

Below the permanent thermocline, the slopes of the isotherms can be used to separate the section into two regions. The 10°C isotherm is typical. In the western part of the section from Honolulu to about 1,800 km it generally changed depth by less than 50 m, i.e., the slope was less than 3 m/100 km. In the eastern part of the section, from a point at 2,200 km on the section to near San Francisco (3,800 km) the depth of the 10°C isotherm decreased by 150 to 200 m, or a slope of greater than 9 m/100 km. The smaller slopes are associated with the Eastern North Pacific Central waters, while the steeper slopes were associated with both the California Current and Transition Zone regions.

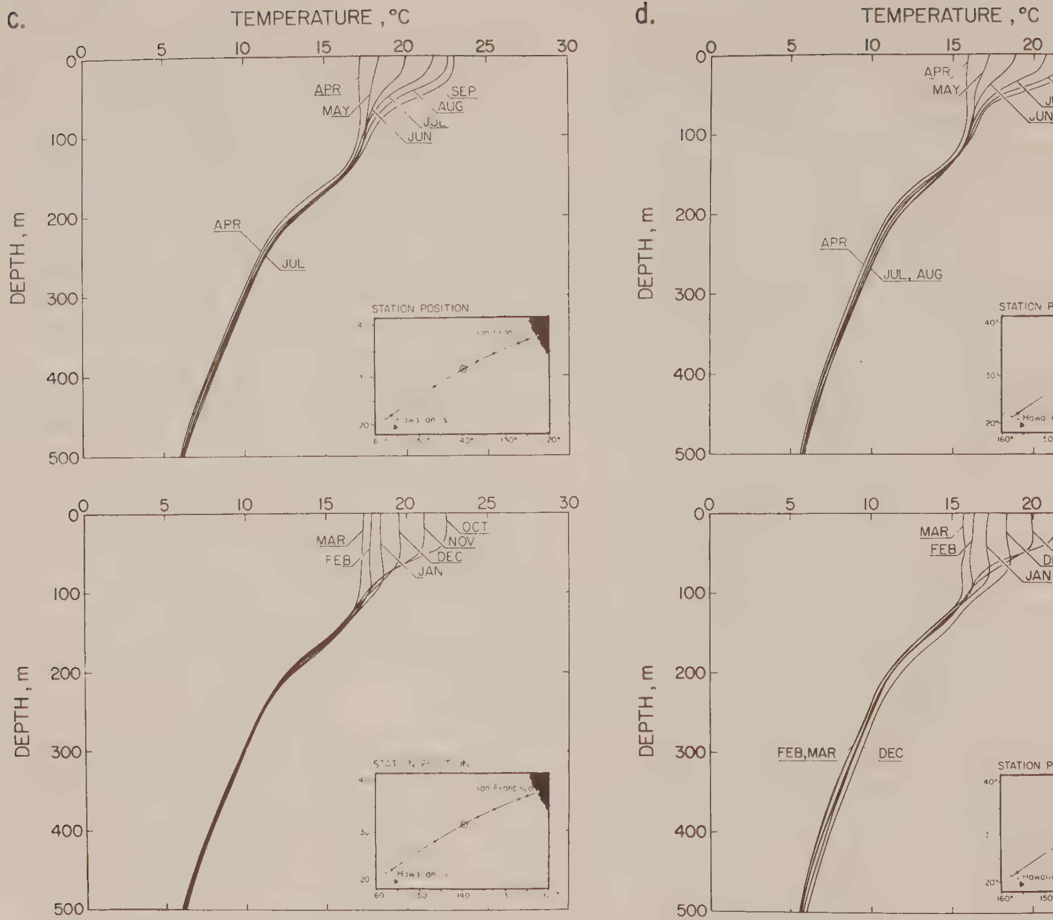


Figure 4.—Continued.

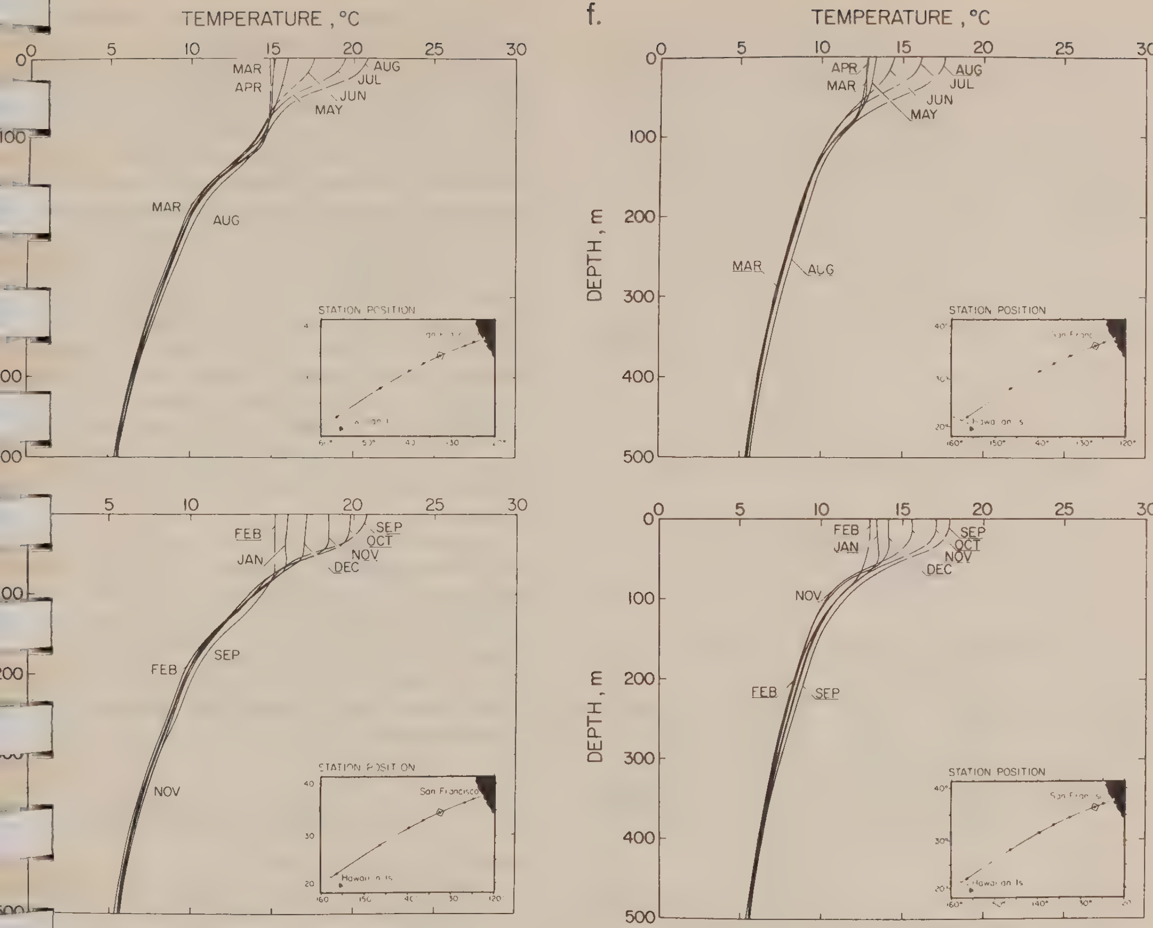
Coastal Upwelling

Reid et al. (1958) have described upwelling and the subsurface countercurrent along the California coast from repeated detailed oceanographic observations by the California Cooperative Oceanic Fisheries Investigations (CalCOFI) program. Some effects of upwelling also appear in XBT mean temperatures, although sampling was poor at the California end of the route. In January, Appendix 1, the 9°C isotherm was closest to the surface (about 130 m) some 200 km from the California coast, but bent downward to 150 m at the coast. About late March the 9°C isotherm began to rise and reached a depth of about 120 m at the coast by mid-June, so that it then had nearly a uniform upward trend approaching the coast. Starting in September it began to sink again at the coast and the "ridge" in the isotherm again moved gradually offshore and by mid-November had returned to the position 200 km offshore where it was in January.

Coastal upwelling causes a delay in the onset of summer warming and a reduced range of the seasonally varying mean temperature. In the inshore area of the California Current (Fig. 3g), after a nearly constant winter temperature of about 12°C, summer warming at the surface did not begin until late May or earl
pared with April or May farther offshore (
in the inshore area the September tem
imum reached only 16°C, for an annua
4°C, whereas farther offshore (Fig. 3f) it
for an annual range exceeding 5°C.

California Subsurface Countercurr

In the vertical sections of Appendix 1
ing of the 6°, 7°, and 8°C isotherms from
the California coast shows warmer wa
coast (at depths of 200 to 500 m) than
agrees with observations of Reid et
reported the existence of a narrow nor
undercurrent against the California coas
m. An exception occurred during April
the 8°C isotherm rose to about 200 m at
indicates that upwelling normally reache
during these months. Another exception
level approach to the coast of the 8°C isot
August to mid-September. This may refl
summer upwelling period, but might just
inadequate sampling immediately adjace



Continued.

30-Day Temperature Changes

er panels of the figures in Appendix 1 show f temperature change in the upper 200 m dur- 0-day periods (of a 360-day yr). The maximum rate g was 2°C/mo in June at the surface near 2,600 is in the Transition Zone. The maximum rate was just over 1.5°C/mo during November and mber in the same area. The rate of cooling was cause the cooling takes place over a depth of at whereas the warming is confined to a shal- layer of about 25 m. There was very little erature change at any depth throughout the section March to mid-April, but there was no cor- period in the fall.

the fall period the downward mixing of heat into the thermocline as the surface cools is evident over route in the temperature changes (Appendix he vertical profiles (Fig. 4a-g). Beginning in st a subsurface maximum of warming appeared just 50 m throughout most of the section. The level of warming moved downward during the fall 00 m in December. During this time the sur- was cooling and a strong gradient of temperature veloped between the surface cooling and the subsurface warming. The maximum subsurface warming decreased as its depth increased with time, and subsurface warming essentially disappeared by February.

The patterns of temperature change in the California Current region differ from those over most of the section. For example, from September through November and at distances of 3,200 to 3,400 km along the route, cooling extended downward from the surface to 200 m, at least. This created a break in the pattern of the warming maximum at 50 m, which existed over the rest of the section. A secondary center of cooling below 100 m occurred at 2,700 to 2,900 km on the route. These changes were associated with the development of a wave pattern in the isotherms along the permanent thermocline. The centers of cooling were associated with a steepening of the slope of the isotherms in the corresponding vertical sections, whereas in between these centers the isotherms flatten out. The steepening and flattening indicate a splitting of the broad flow of the California Current into filaments of stronger and weaker flow, respectively. The cooling pattern propagated westward along the section at a speed of about 100 km/mo (3.8 cm/s).

There was a counterpart center of warming which appeared in mid-December in the California Current region (around 3,400 km and 90 m) and which could be followed

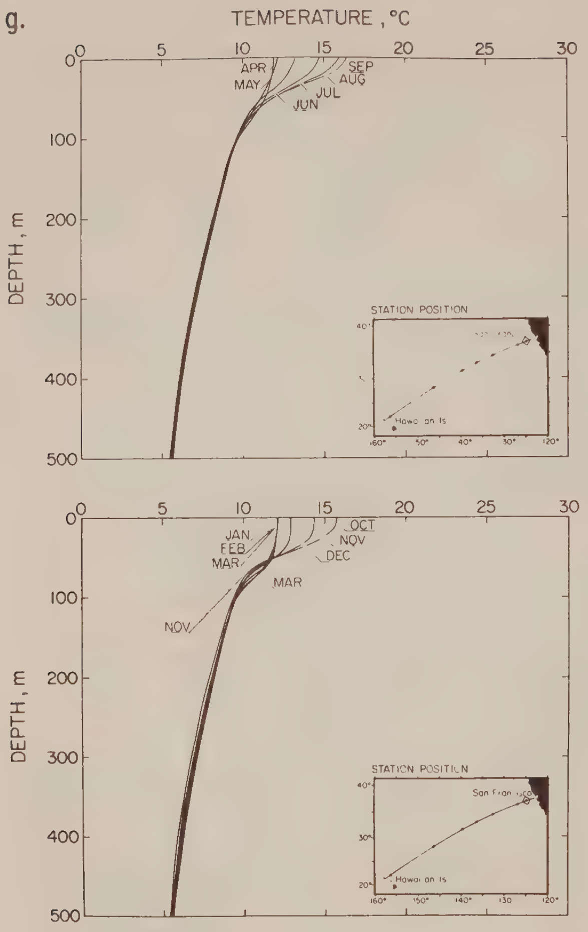


Figure 4.—Continued.

through early April propagating westward, also at the rate of 100 km/mo. This warming, however, was associated with the disappearance of the previously mentioned wave pattern along the thermocline.

From considerations of heat balance we may infer from the patterns of temperature changes that over most of the section vertical mixing dominates in transmitting the surface warming-cooling cycle downward to subsurface levels of 100 to 150 m. In contrast, horizontal advection of heat may be dominant in the California Current to depths of 200 to 300 m. The cause of the growth and decay of the wave pattern on the thermocline in the eastern part of the sections should be investigated.

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The cooperation of the shipping companie
sonnel of ships listed in Table 1 is grat
acknowledged. Special recognition is due L. E. Ingr
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board routine and to shakedown a new, and som
seemingly capricious, oceanographic instrum

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Oceanography.

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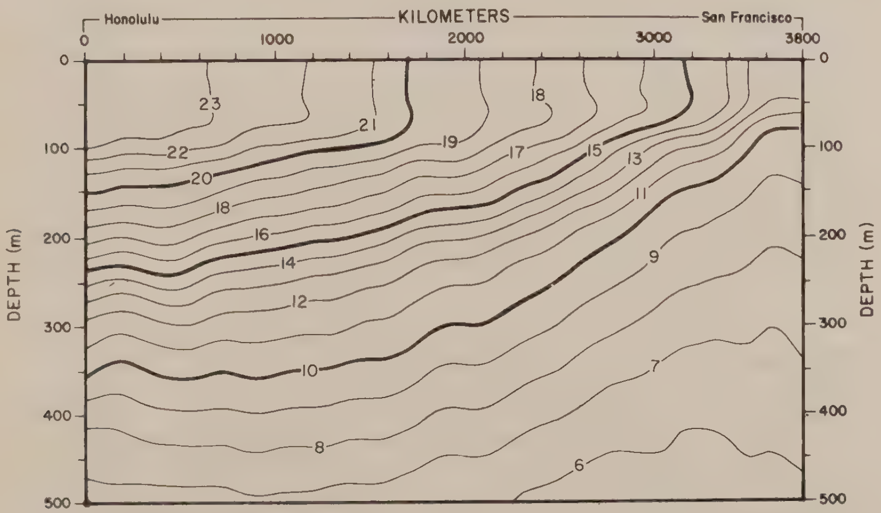
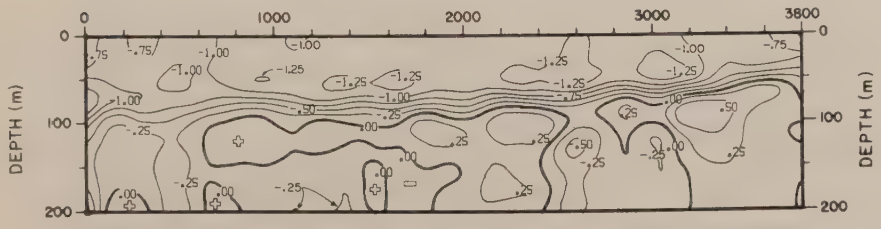
APPENDIX 1

Vertical Sections of Mean Temperature and Mean "30-day" Temperature Change

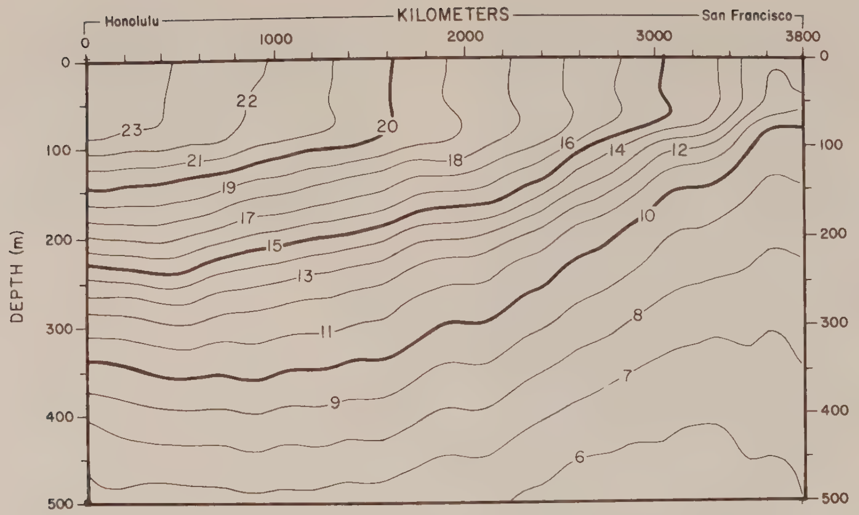
pendix contains 24 vertical sections of mean temperature (°C), from the surface to 500 m, between San nd Honolulu (upper panel) and spaced at 15-day intervals of a 360-day yr. The lower panel is a vertical sec- 200 m showing the 30-day changes in temperature and centered on the date of the temperature section above it. onvenience the sections are labeled as: 01 January, mid-January, 01 February, etc., through mid-December. s of mean temperature were spatially smoothed, as explained in the text, before being contoured.



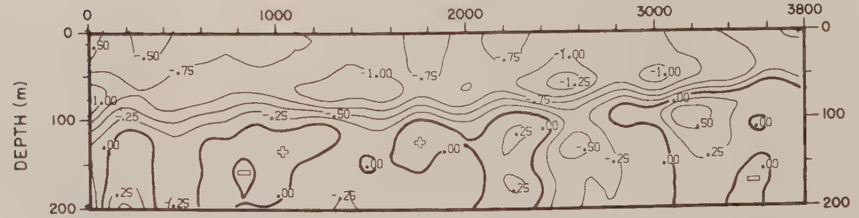
MEAN XBT TEMPERATURE, DEG-C 01 JANUARY



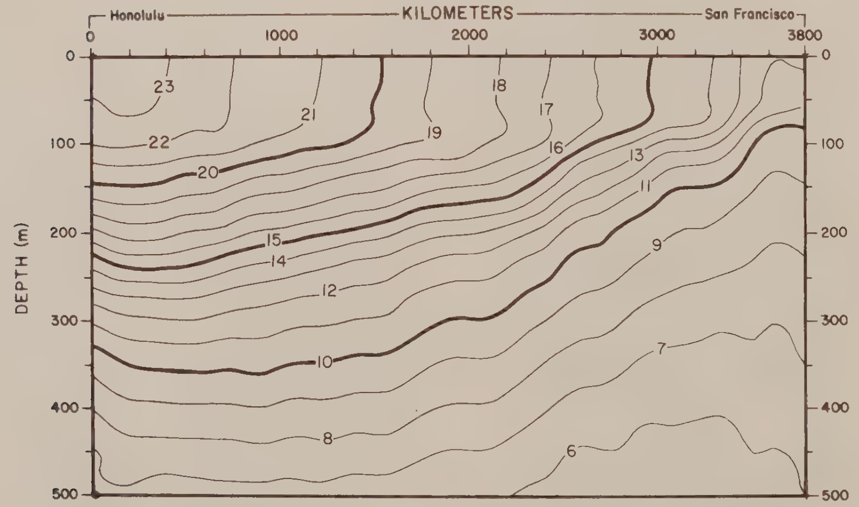
MEAN XBT TEMPERATURE CHANGE, DEG-C MID-DECEMBER TO MID-JANUARY



MEAN XBT TEMPERATURE, DEG-C MID-JANUARY



MEAN XBT TEMPERATURE CHANGE, DEG-C 01 JANUARY TO 01 FEBRUARY



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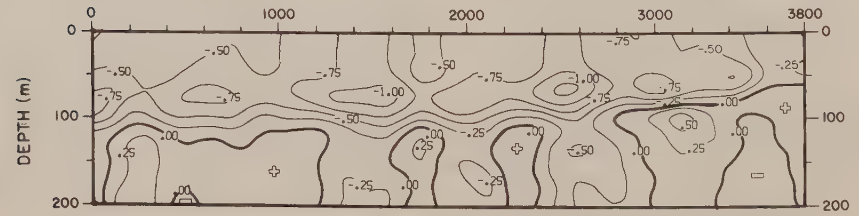
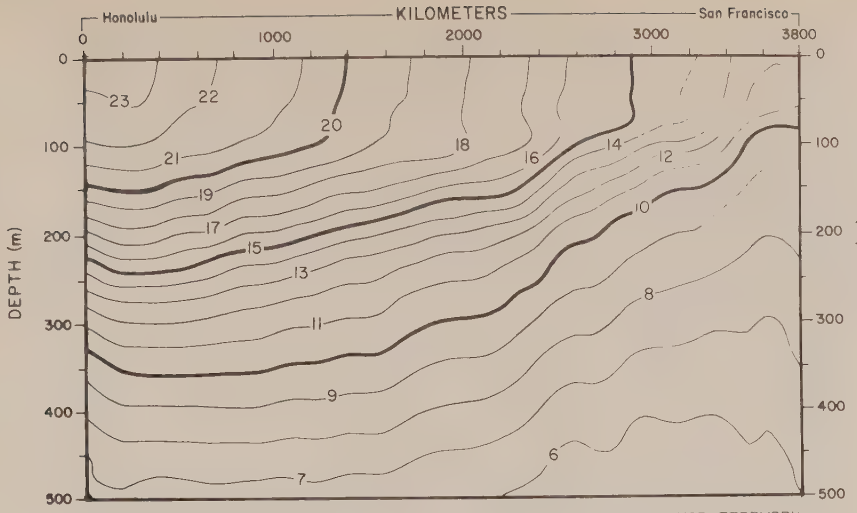
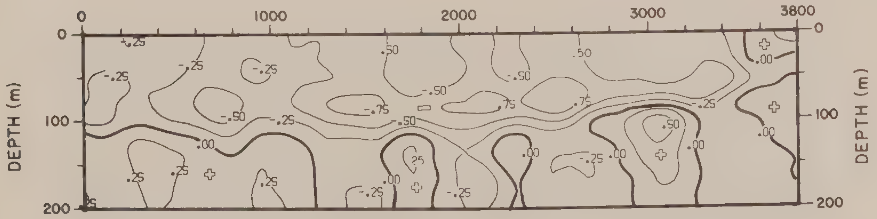


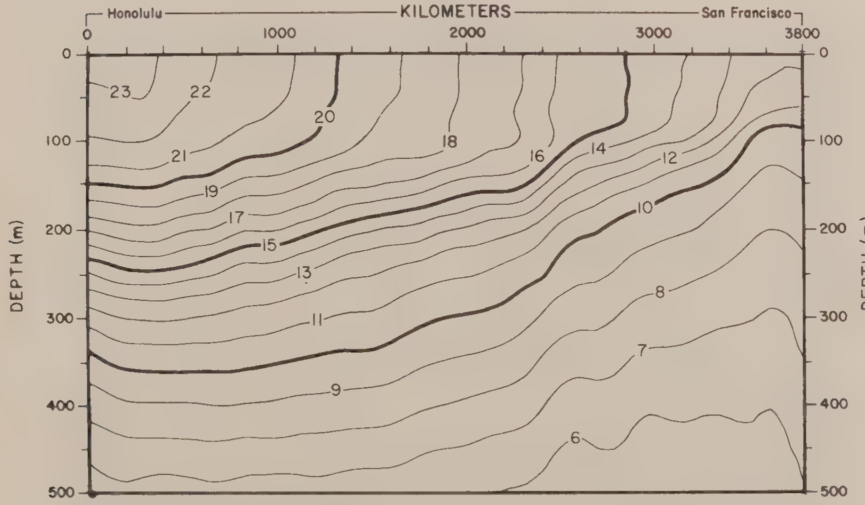
MEAN XBT TEMPERATURE CHANGE, DEG-C MID-JANUARY TO MID-FEBRUARY



MEAN XBT TEMPERATURE, DEG-C MID-FEBRUARY



MEAN XBT TEMPERATURE CHANGE, DEG-C 01 FEBRUARY TO 01 MARCH



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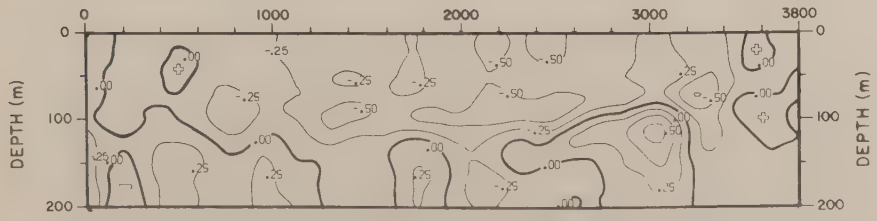

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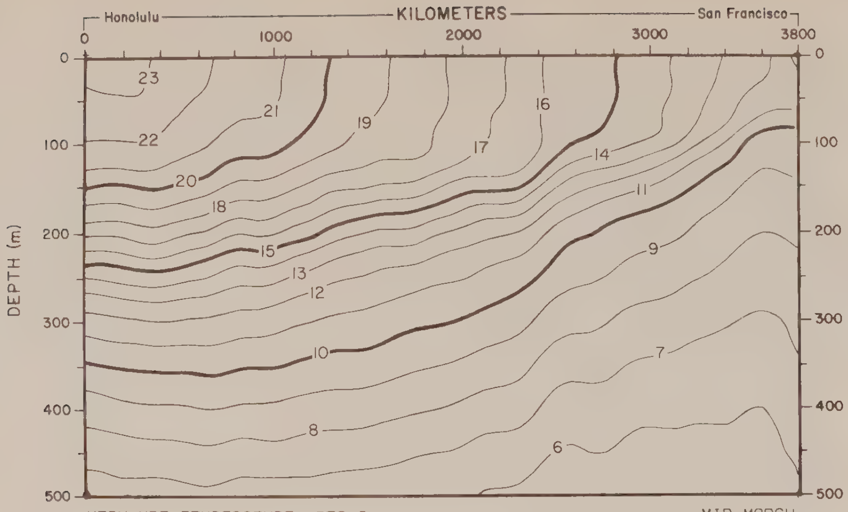

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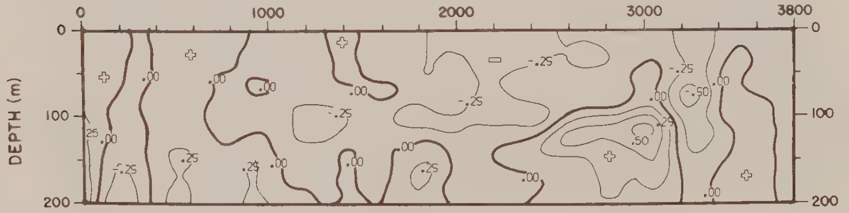

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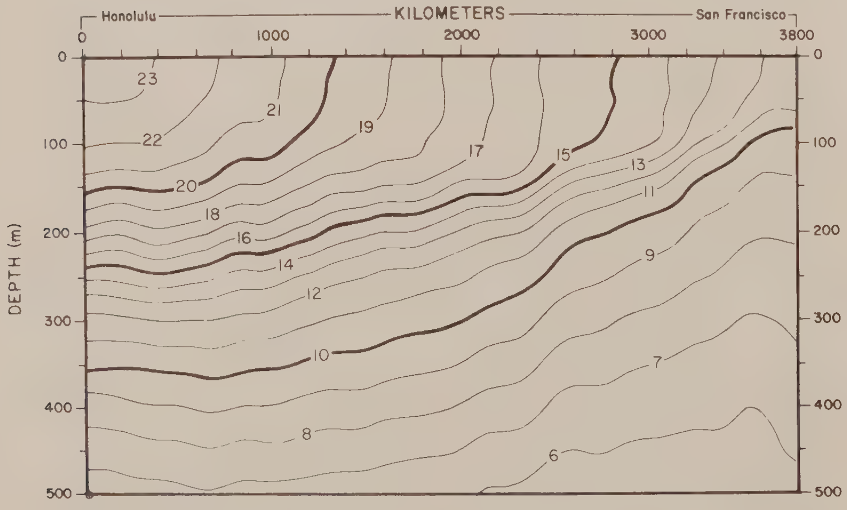

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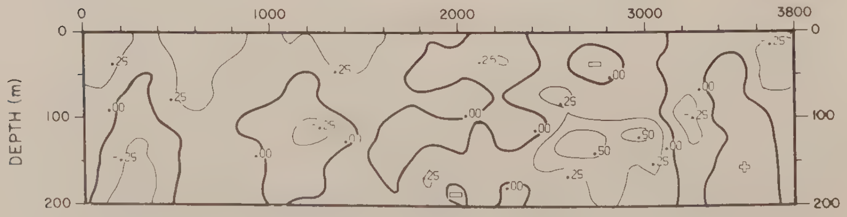

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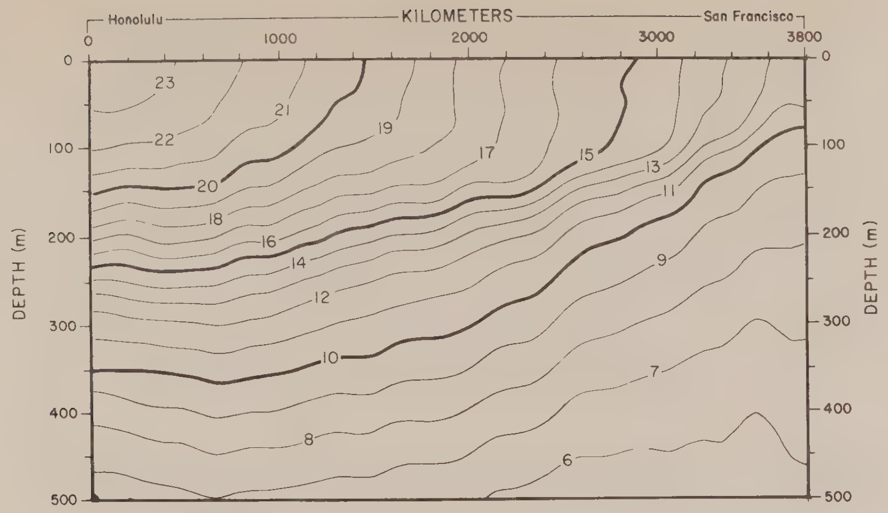

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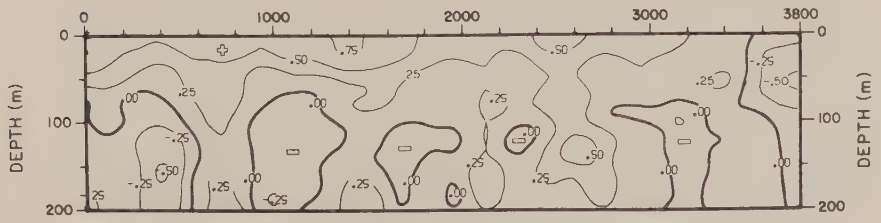

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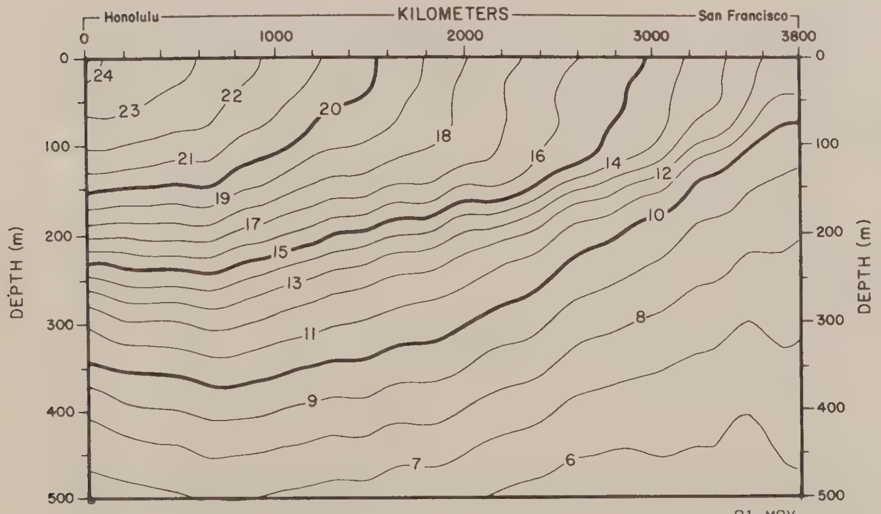

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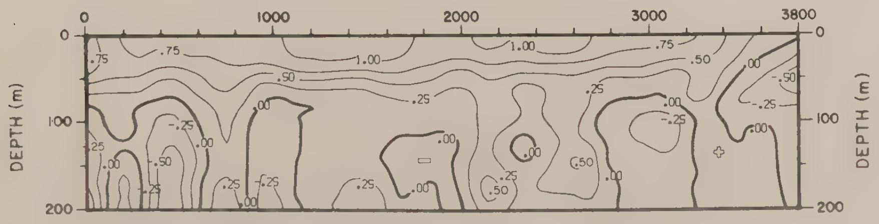

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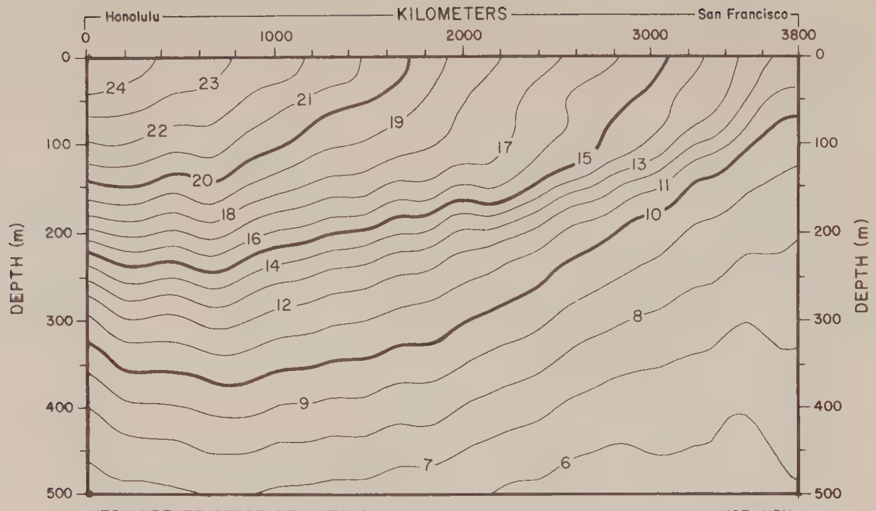

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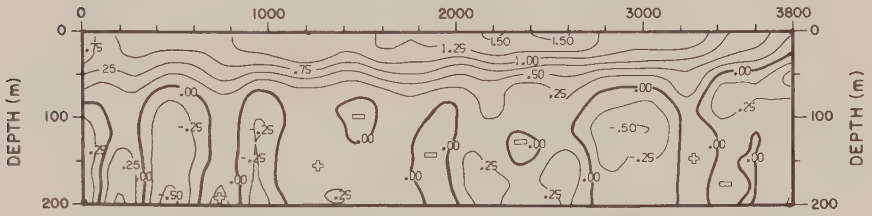

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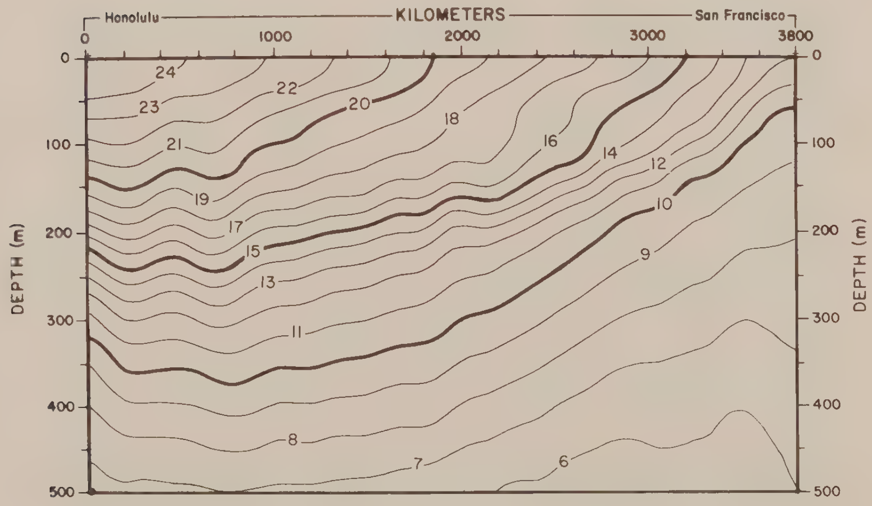

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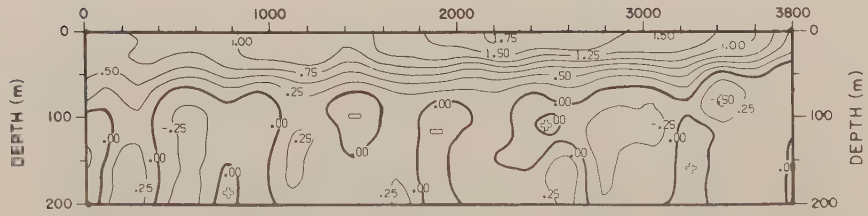

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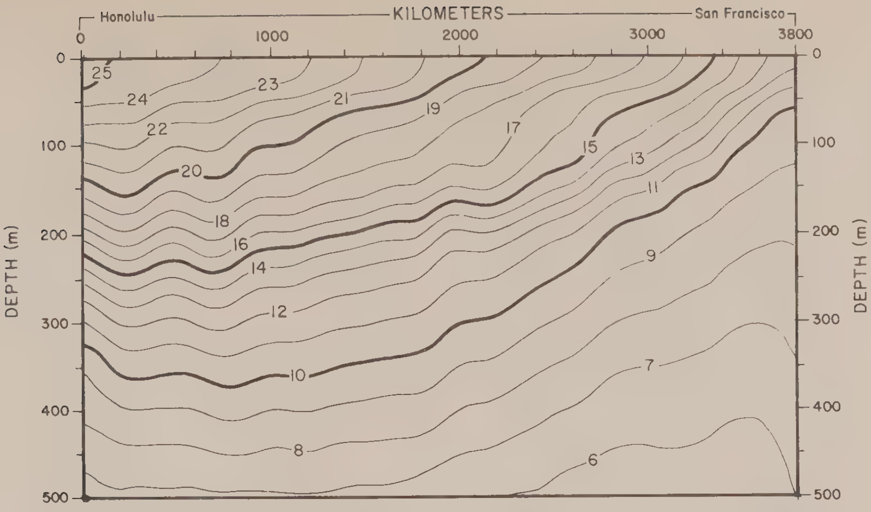

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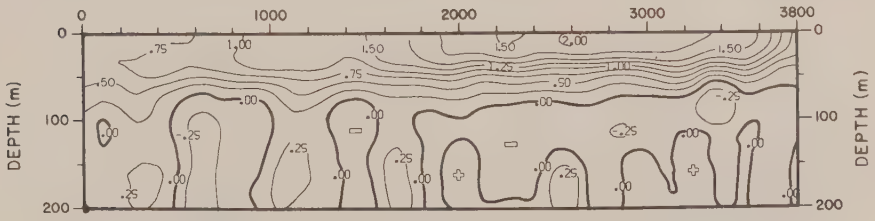
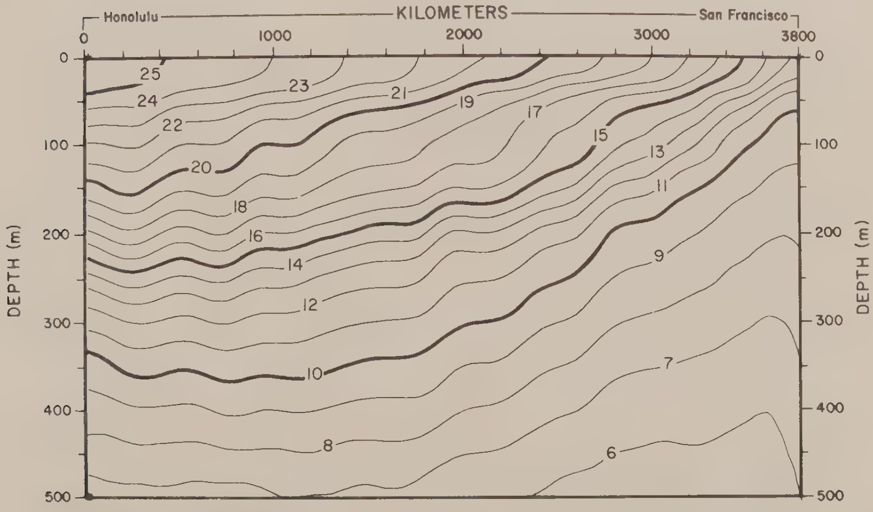


MEAN XBT TEMPERATURE CHANGE, DEG-C 01 JUNE TO 01 JULY



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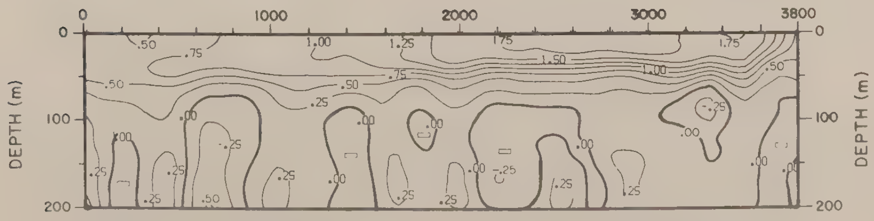

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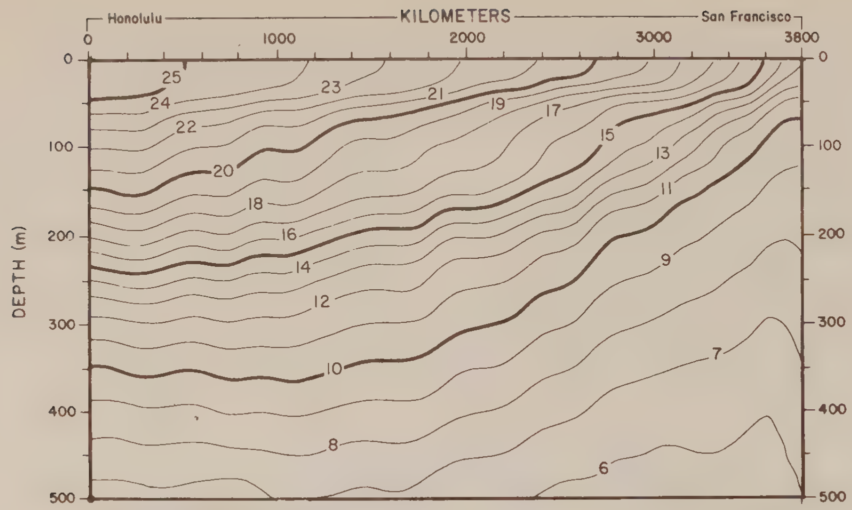

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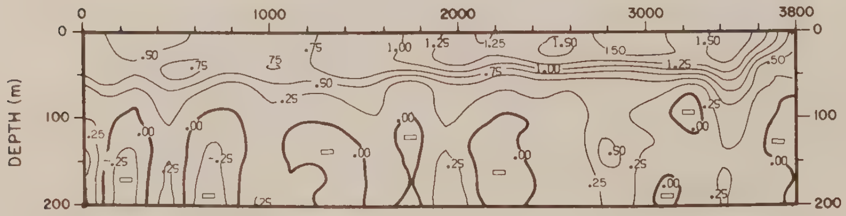

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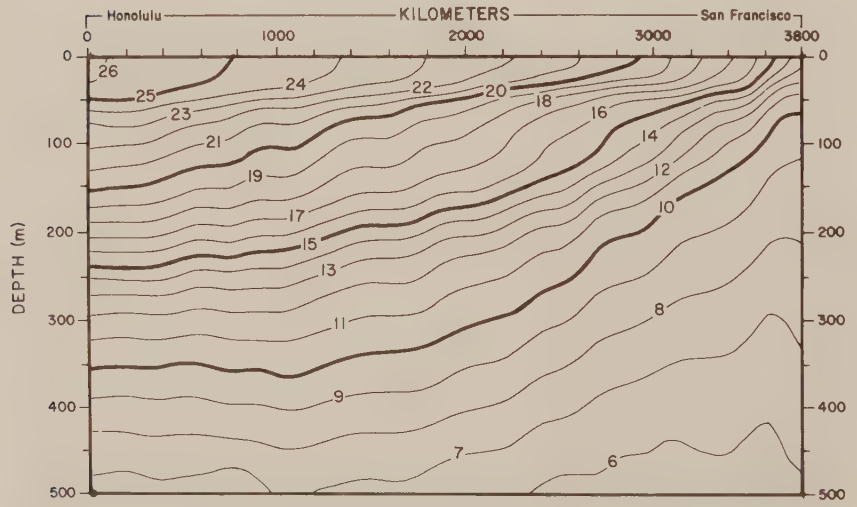

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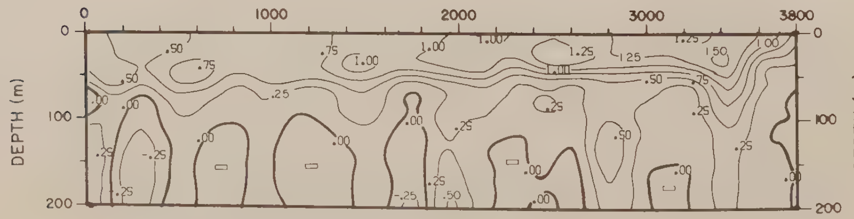

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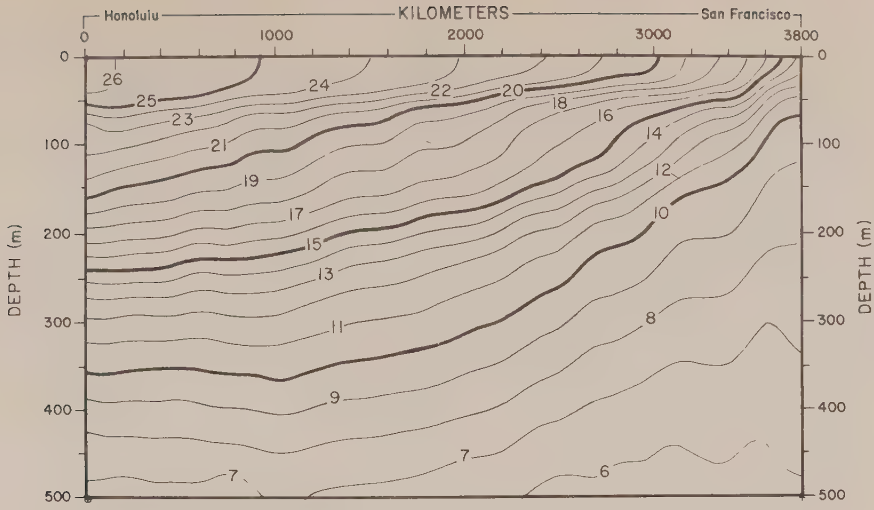

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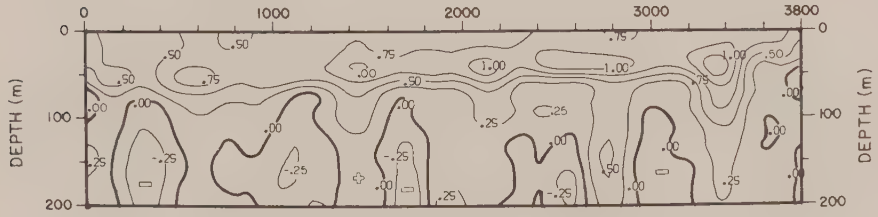

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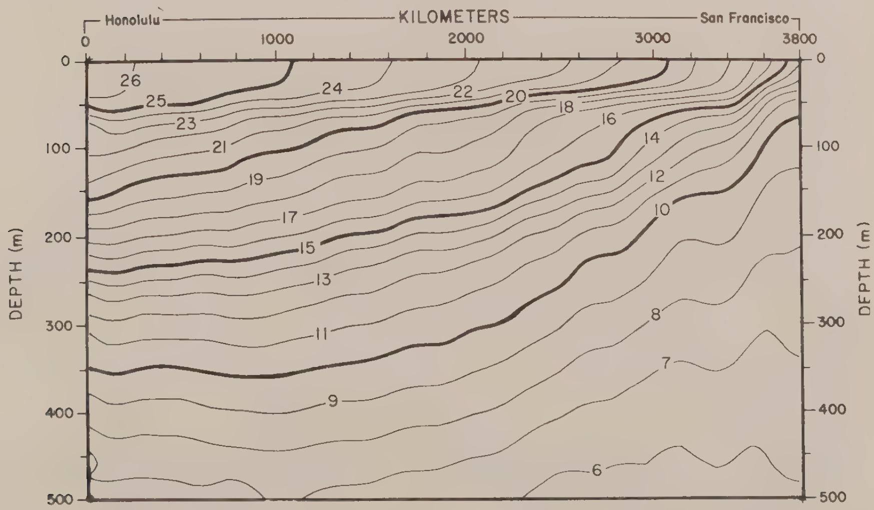

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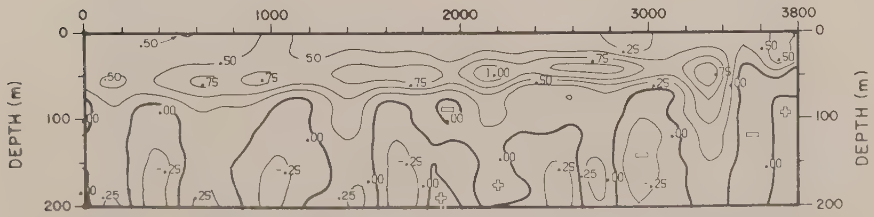

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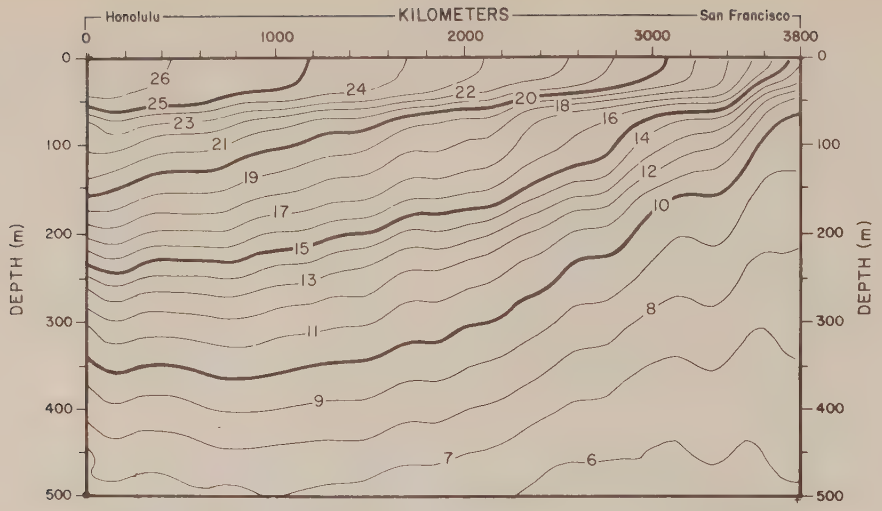

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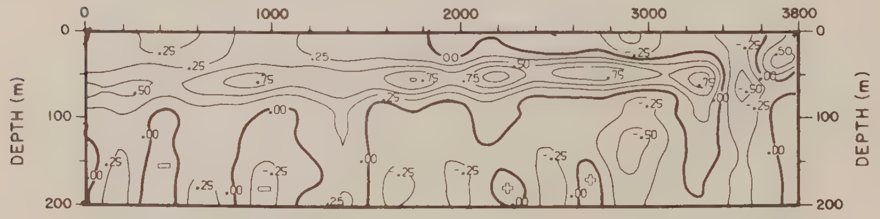
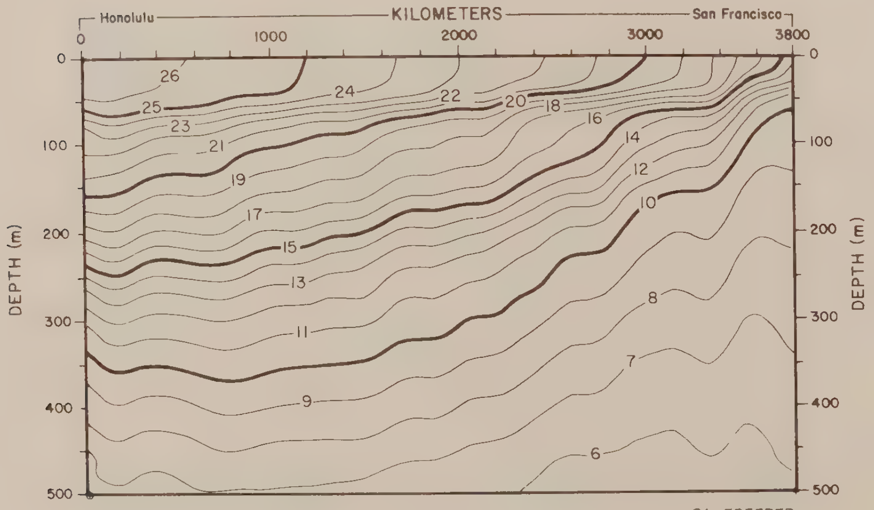


MEAN XBT TEMPERATURE CHANGE, DEG-C 01 SEPTEMBER TO 01 OCTOBER



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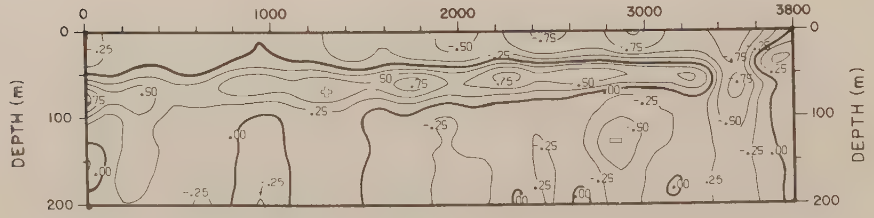

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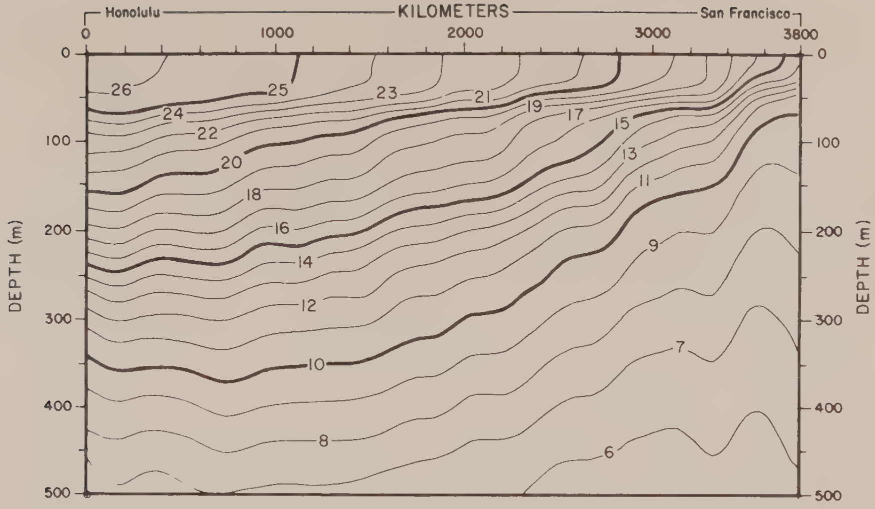

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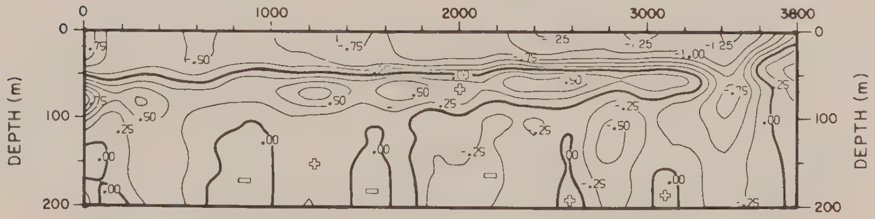

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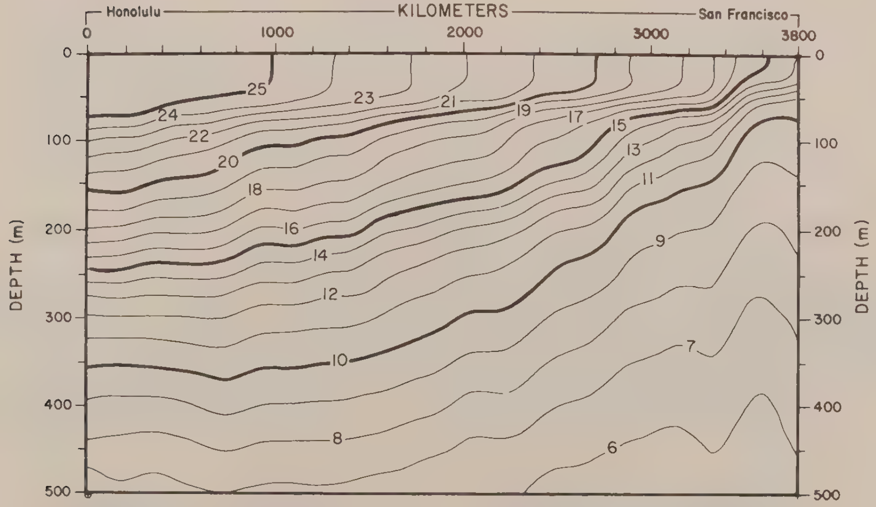

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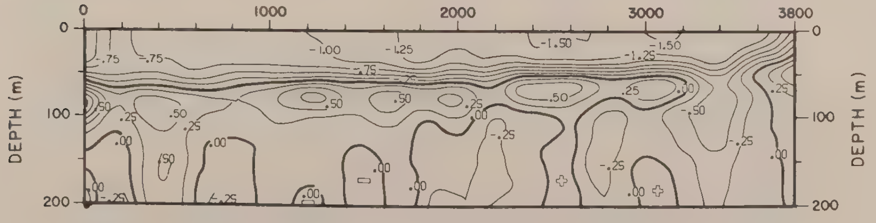

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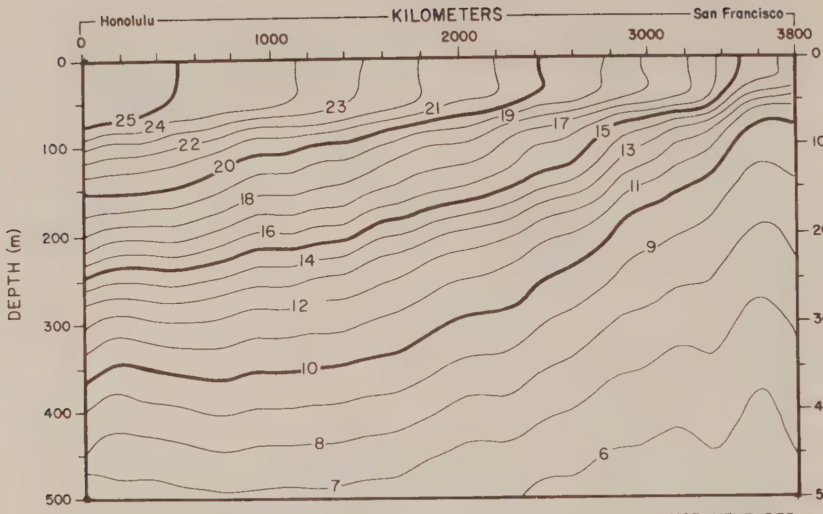

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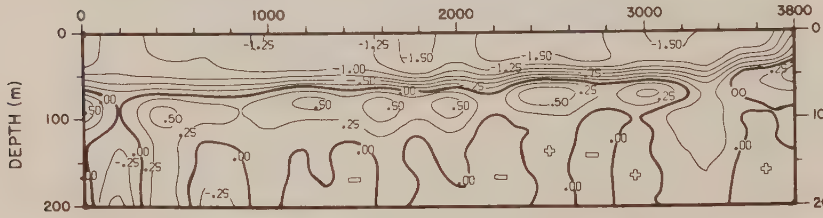
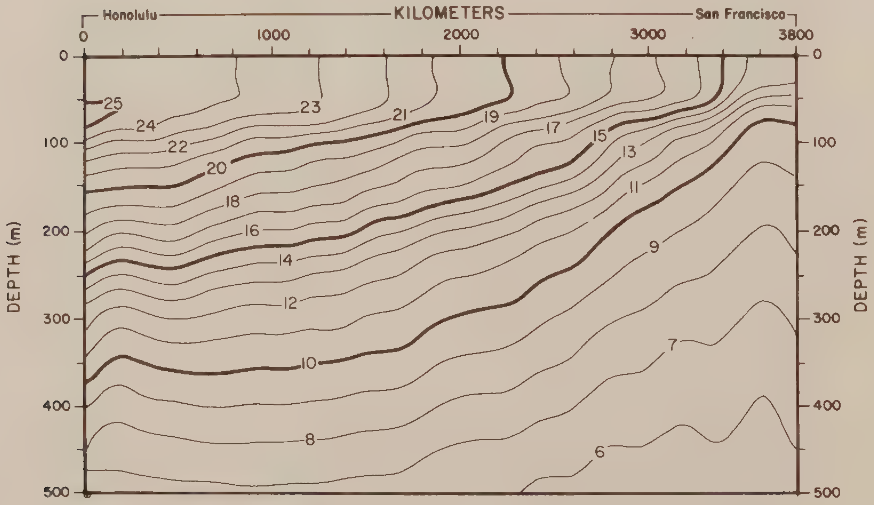
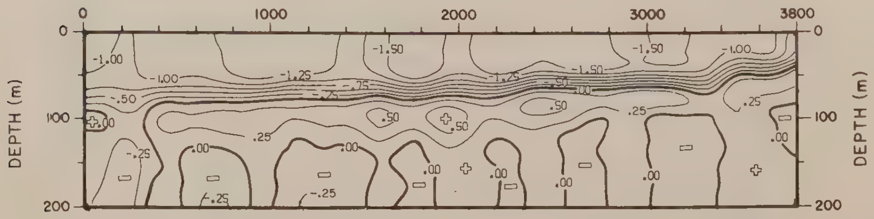


MEAN XBT TEMPERATURE CHANGE, DEG-C 01 NOVEMBER TO 01 DECEMBER



MEAN XBT TEMPERATURE, DEG-C 01 DECEMBER



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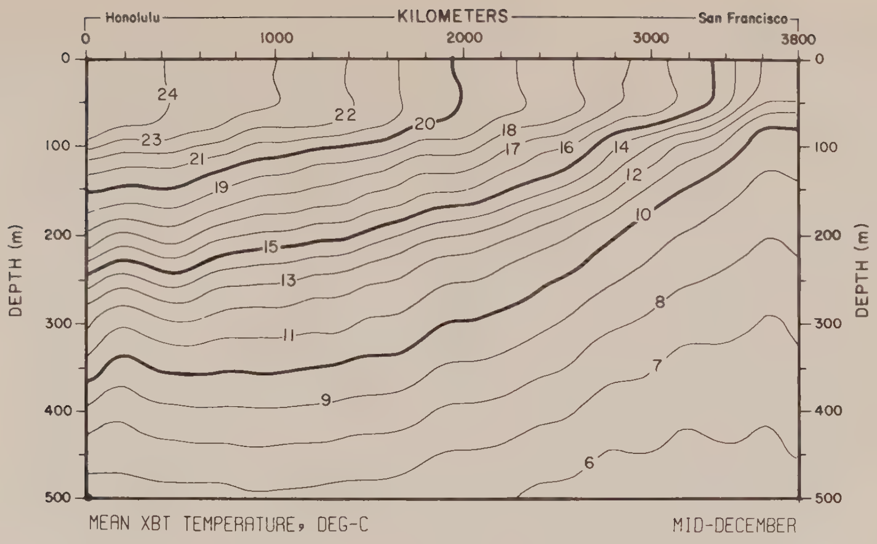

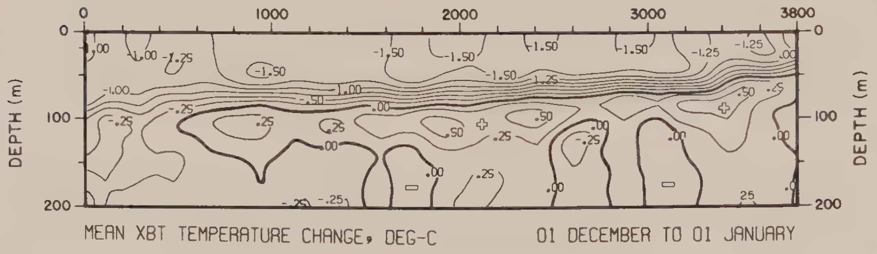

APPENDIX 2

Tables of Mean XBT Temperature

This Appendix contains 24 tables of mean temperatures (°C) spaced at equal intervals throughout the year rresponding to the temperature sections of Appendix 1. Each table contains, at alternating grid points, i.e., interval 185 km (100 n.mi.) on the San Francisco-Honolulu route, the mean temperature for selected depths, in meters. The ean temperatures are those computed from the fitted three-component harmonic function for the given distance an pth. These temperatures were abstracted from the complete grid, without smoothing.

MEAN XBT TEMPERATURE, DEG-C

01 JANUARY

	0	23.9	23.9	23.2	23.0	22.6	22.3	21.8	21.4	20.9	19.8	19.3	18.9	18.2	17.7	16.7	16.4	15.5	14.9	13.7	12.3
	10	23.9	23.8	23.2	23.0	22.6	22.3	21.8	21.4	20.8	19.8	19.3	18.9	18.2	17.6	16.7	16.3	15.5	14.9	13.8	12.3
	20	23.9	23.8	23.2	23.1	22.5	22.3	21.8	21.4	20.8	19.7	19.3	18.9	18.2	17.6	16.7	16.3	15.5	15.0	13.8	12.2
	30	23.9	23.8	23.2	23.1	22.5	22.3	21.8	21.4	20.8	19.7	19.3	18.9	18.1	17.6	16.8	16.2	15.5	15.0	13.8	12.2
	40	23.9	23.8	23.2	23.1	22.5	22.2	21.8	21.3	20.8	19.7	19.3	18.9	18.1	17.7	16.9	16.1	15.6	15.0	13.9	12.1
	50	24.0	23.8	23.2	23.1	22.5	22.2	21.8	21.4	20.9	19.7	19.3	19.0	18.3	17.8	17.0	16.3	15.7	15.0	13.9	11.9
D	60	24.0	23.7	23.2	23.1	22.5	22.2	21.9	21.4	20.9	19.8	19.4	19.0	18.4	17.9	17.1	16.2	15.7	14.8	13.5	11.4
E	70	24.0	23.7	23.2	23.1	22.4	22.1	21.9	21.4	21.0	19.8	19.5	18.9	18.3	17.8	16.8	15.7	15.4	14.5	12.8	10.6
P	80	23.8	23.4	23.1	22.9	22.1	21.8	21.6	21.1	20.7	19.6	19.4	18.8	18.0	17.5	16.4	15.4	14.4	13.7	11.9	10.0
T	90	23.3	22.9	22.8	22.5	21.6	21.4	21.0	20.7	20.2	19.2	19.2	18.4	17.6	17.0	15.7	14.5	13.3	12.7	11.3	9,7
H	100	22.8	22.4	22.3	22.0	21.1	20.8	20.3	20.1	19.7	18.8	18.8	17.9	17.2	16.4	15.0	13.9	12.6	12.0	11.0	9.5
	120	21.5	21.1	21.1	20.6	20.1	19.7	19.1	18.9	18.6	17.5	17.9	17.1	16.2	15.3	14.2	13.0	11.7	11.0	10.1	9.1
(M)	150	20.0	19.6	19.7	19.2	18.6	18.2	17.7	17.4	17.0	16.2	16.2	15.8	14.7	13.9	12.8	11.6	10.4	9.9	9.4	8.8
	200	17.2	17.2	17.4	16.5	16.1	15.8	15.2	15.0	14.5	13.4	13.2	12.9	12.0	11.3	10.5	9.9	9.2	9.0	8.6	8.1
	250	13.9	14.1	14.7	13.6	13.4	13.2	12.7	12.5	12.3	11.6	11.1	11.0	10.4	10.0	9.4	9.0	8.4	8.1	7.9	7.5
	300	11.4	11.5	11.9	11.6	11.6	11.5	11.2	11.1	10.9	10.5	9.9	9.9	9.4	9.0	8.4	8.0	7.6	7.4	7.2	7.0
	400	8.4	8.6	8.8	8.9	8.9	8.9	8.8	8.6	8.6	8.3	7.8	7.8	7.4	7.1	6.7	6.5	6.4	6.2	6.2	6.2
	500	6.7	6.6	6.6	6.6	6.8	6.8	6.7	6.5	6.6	6.4	6.2	6.3	5.9	5.7	5.5	5.6	5.5	5.5	5.6	5.5
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

DISTANCE

MEAN XBT TEMPERATURE, DEG-C

MID-JANUARY

	0	23.6	23.6	22.9	22.7	22.2	21.9	21.5	20.9	20.4	19.4	18.9	18.5	17.8	17.2	16.4	15.9	15.0	14.6	13.4	12.1
	10	23.6	23.6	22.9	22.7	22.2	21.9	21.5	20.9	20.4	19.4	18.9	18.5	17.7	17.2	16.3	15.9	15.0	14.5	13.5	12.0
	20	23.6	23.6	22.9	22.7	22.1	21.9	21.4	20.9	20.4	19.4	18.9	18.5	17.7	17.1	16.3	15.9	15.0	14.6	13.5	11.9
	30	23.6	23.6	22.8	22.7	22.1	21.9	21.4	20.9	20.3	19.3	18.9	18.5	17.7	17.1	16.4	15.8	14.9	14.5	13.5	11.9
	40	23.6	23.5	22.8	22.7	22.1	21.8	21.4	20.8	20.3	19.3	18.8	18.5	17.6	17.1	16.5	15.7	15.0	14.5	13.6	11.9
	50	23.5	23.5	22.8	22.7	22.0	21.8	21.4	20.8	20.3	19.3	18.9	18.5	17.7	17.2	16.5	15.8	15.1	14.6	13.6	11.8
D	60	23.5	23.4	22.8	22.7	22.0	21.7	21.4	20.8	20.4	19.4	19.0	18.6	17.8	17.3	16.6	15.9	15.2	14.5	13.4	11.5
E	70	23.5	23.3	22.8	22.7	22.0	21.7	21.4	20.9	20.4	19.4	19.1	18.6	17.9	17.3	16.6	15.7	15.1	14.5	12.8	10.8
P	80	23.3	23.0	22.7	22.6	21.9	21.6	21.2	20.8	20.3	19.4	19.1	18.6	17.9	17.3	16.3	15.5	14.3	13.9	12.1	10.1
T	90	23.1	22.6	22.4	22.3	21.6	21.3	20.9	20.5	20.0	19.3	19.0	18.4	17.7	17.0	15.7	14.7	13.3	13.0	11.5	9.8
H	100	22.6	22.2	22.1	21.9	21.2	20.8	20.3	20.0	19.5	19.0	18.8	18.0	17.3	16.4	15.0	14.0	12.5	12.3	11.1	9.6
	120	21.4	21.1	21.0	20.7	20.2	19.8	19.2	18.9	18.6	17.7	18.0	17.1	16.2	15.1	14.0	13.0	11.5	11.1	10.3	9.2
(M)	150	20.0	19.7	79.5	19.3	18.6	18.2	17.7	17.3	17.1	16.2	16.2	15.9	14.8	13.7	12.7	11.5	10.2	10.0	9.5	8.8
	200	17.3	17.4	17.2	16.7	16.1	15.8	15.2	14.9	14.5	13.4	13.3	12.9	12.0	11.1	10.5	9.8	9.1	9.0	8.6	8.1
	250	14.1	14.3	14.6	13.8	13.5	13.2	12.7	12.4	12.3	11.5	11.1	11.0	10.4	9.9	9.4	8.9	8.4	8.2	7.9	7.6
	300	11.5	11.7	11.9	11.7	11.6	11.4	11.2	11.1	11.0	10.4	9.9	10.0	9.3	8.9	8.4	8.0	7.5	7.4	7.2	7.0
	400	8.4	8.7	8.9	8.9	9.0	8.8	8.8	8.6	8.7	8.2	7.9	7.9	7.3	7.0	6.6	6.4	6.3	6.2	6.1	6.3
	500	6.8	6.6	6.6	6.7	6.7	6.7	6.8	6.5	6.6	6.4	6.2	6.3	5.8	5.6	5.5	5.5	5.5	5.4	5.5	5.5
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

DISTANCE

MEAN XBT TEMPERATURE, DEG-C

01 FEBRUARY

	0	23.4	23.5	22.7	22.4	21.9	21.7	21.2	20.4	19.9	19.1	18.6	18.2	17.4	16.8	16.1	15.5	14.6	14.3	13.2	12.1
	10	23.3	23.4	22.7	22.4	21.9	21.6	21.1	20.4	19.9	19.1	18.5	18.2	17.4	16.7	16.0	15.4	14.6	14.2	13.2	12.0
	20	23.3	23.4	22.6	22.4	21.8	21.6	21.1	20.4	19.9	19.1	18.5	18.1	17.4	16.7	16.0	15.4	14.5	14.2	13.2	11.9
	30	23.3	23.4	22.6	22.4	21.8	21.6	21.1	20.4	19.9	19.1	18.5	18.1	17.3	16.6	16.1	15.4	14.5	14.1	13.2	11.9
	40	23.2	23.3	22.5	22.3	21.8	21.5	21.0	20.3	19.9	19.1	18.4	18.1	17.3	16.6	16.1	15.4	14.5	14.1	13.2	11.8
	50	23.2	23.3	22.5	22.4	21.7	21.4	21.0	20.2	19.8	19.0	18.5	18.1	17.2	16.5	16.0	15.4	14.5	14.1	13.2	11.8
D	60	23.1	23.1	22.4	22.3	21.7	21.3	20.9	20.2	19.8	19.0	18.5	18.1	17.3	16.		15.5	14.6	14.2	13.0	11.5
E	70	23.0	23.0	22.4	22.3	21.6	21.3	20.8	20.3	19.7	19.1	18.6	18.2	17.4	16.7	16.1	15.5	14.6	14.3	12.7	10.9
P	80	22.9	22.7	22.2	22.2	21.6	21.2	20.8	20.3	19.7	19.1	18.6	18.2	17.5	16.7	16.0	15.4	14.1	13.9	12.1	10.2
T	90	22.7	22.4	22.0	22.0	21.4	21.0	20.7	20.1	19.5	19.2	18.6	18.2	17.5	16.6	15.6	14.8	13.4	13.2	11.6	9.8
H	100	22.3	22.0	21.8	21.7	21.1	20.7	20.3	19.8	19.2	19.0	18.6	17.9	17.3	16.3	14.9	14.1	12.6	12.5	11.2	9.6
	120	21.3	21.2	20.9	20.7	20.2	19.8	19.3	18.9	18.5	17.9	18.0	17.1	16.3	15.0	13.8	12.9	11.5	11.2	10.4	9.2
(M)	150	19.9	19.8	19.4	19.4	18.6	18.4	17.8	17.3	17.1	16.4	16.1	15.8	14.8	13.5	12.6	11.4	10.1	10.1	9.5	8.8
	200	17.4	17.6	17.1	16.9	16.1	15.9	15.3	14.7	14.4	13.5	13.3	12.9	12.0	10.9	10.4	9.7	9.1	9.0	8.6	8.1
	250	14.3	14.5	14.6	14.0	13.5	13.2	12.8	12.4	12.2	11.5	11.1	11.1	10.4	9.7	9.3	8.8	8.3	8.2	7.9	7.6
	300	11.7	11.9	12.0	11.8	11.6	11.4	11.3	11.0	11.0	10.3	9.9	10.0	9.3	8.8	8.3	7.8	7.5	7.4	7.2	7.0
	400	8.6	8.8	8.9	8.9	9.0	8.8	8.8	8.6	8.7	8.2	7.9	7.9	7.3	6.8	6.6	6.2	6.2	6.1	6.2	6.2
	500	6.9	6.6	6.6	6.7	6.6	6.6	6.7	6.5	6.6	6.4	6.1	6.2	5.9	5.5	5.4	5.4	5.4	5.3	5.4	5.6
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

DISTANCE

MEAN XBT TEMPERATURE, DEG-C

MID-FEBRUARY

	0	23.3	23.3	22.7	22.3	21.7	21.5	20.9	20.0	19.6	19.0	18.3	17.9	17.2	16.4	15.8	15.1	14.3	14.0	13.1	12.1
	10	23.2	23.3	22.6	22.3	21.7	21.5	20.9	20.0	19.6	19.0	18.3	17.9	17.2	16.3	15.8	15.1	14.3	13.9	13.1	12.1
	20	23.2	23.3	22.6	22.2	21.7	21.4	20.9	20.0	19.6	19.0	18.3	17.9	17.1	16.3	15.8	15.1	14.3	13.9	13.0	12.1
	30	23.1	23.3	22.5	22.2	21.6	21.4	20.8	20.0	19.6	18.9	18.2	17.8	17.2	16.2	15.8	15.2	14.3	13.8	13.0	12.0
	40	23.1	23.2	22.4	22.1	21.6	21.3	20.8	19.9	19.5	18.9	18.2	17.8	17.1	16.2	15.8	15.2	14.2	13.8	12.9	11.8
	50	23.0	23.2	22.3	22.1	21.5	21.2	20.7	19.9	19.5	19.0	18.2	17.7	17.0	16.1	15.7	15.1	14.2	13.7	12.7	11.7
D	60	22.8	23.0	22.2	22.0	21.4	21.1	20.6	19.8	19.3	18.9	18.2	17.7	16.9	16.0	15.7	15.2	14.2	13.9	12.6	11.5
E	70	22.7	22.8	22.1	21.9	21.3	21.0	20.5	19.8	19.2	18.8	18.2	17.7	17.0	16.1	15.7	15.3	14.2	13.9	12.4	11.0
P	80	22.6	22.6	22.0	21.9	21.3	21.0	20.4	19.8	19.2	18.8	18.2	17.8	17.2	16.2	15.7	15.2	13.9	13.7	12.0	10.3
T	90	22.4	22.3	21.8	21.8	21.2	20.8	20.4	19.7	19.1	18.9	18.2	17.8	17.2	16.2	15.4	14.8	13.5	13.1	11.6	9.9
H	100	22.1	22.0	21.6	21.5	20.9	20.6	20.1	19.5	18.9	18.9	18.3	17.6	17.1	16.0	14.9	14.1	12.8	12.5	11.1	9.6
	120	21.3	21.3	20.9	20.7	20.2	19.9	19.4	18.8	18.3	18.1	17.9	16.9	16.4	14.9	13.6	12.9	11.6	11.3	10.4	9.2
(M)	150	19.9	20.0	19.5	19.5	18.6	18.5	17.9	17.3	17.0	16.6	16.0	15.7	14.9	13.3	12.3	11.3	10.2	10.1	9.4	8.8
	200	17.5	17.7	17.1	17.1	16.1	16.0	15.4	14.6	14.2	13.7	13.2	12.7	12.1	10.7	10.3	9.6	9.2	9.0	8.5	8.1
	250	14.5	14.7	14.6	14.2	13.4	13.3	12.9	12.3	12.1	11.5	11.1	11.0	10.5	9.6	9.2	8.7	8.3	8.2	7.8	7.5
	300	11.9	12.1	12.1	11.9	11.6	11.4	11.3	11.0	10.9	10.3	10.0	9.9	9.3	8.6	8.3	7.7	7.5	7.4	7.2	7.0
	400	8.6	8.9	8.9	9.0	9.0	8.8	8.8	8.6	8.6	8.1	7.9	7.8	7.3	6.7	6.6	6.2	6.2	6.1	6.2	6.1
	500	6.8	6.7	6.7	6.8	6.5	6.5	6.7	6.6	6.6	6.4	6.1	6.1	5.9	5.5	5.5	5.3	5.4	5.3	5.4	5.5
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

DISTANCE

MEAN XBT TEMPERATURE, DEG-C 01 MARCH

	0	23.3	23.2	22.6	22.2	21.6	21.3	20.7	19.8	19.3	18.8	18.1	17.6	17.0	16.0	15.6	14.9	14.2	13.8	13.0	12.2
	10	23.2	23.2	22.6	22.2	21.6	21.3	20.7	19.7	19.3	18.8	18.1	17.6	17.0	15.9	15.5	14.9	14.1	13.7	12.9	12.2
	20	23.1	23.2	22.6	22.1	21.6	21.3	20.6	19.7	19.3	18.8	18.1	17.6	16.9	15.9	15.6	14.9	14.1	13.6	12.9	12.2
	30	23.1	23.2	22.5	22.1	21.5	21.2	20.6	19.7	19.3	18.8	18.1	17.5	17.0	15.9	15.6	15.0	14.2	13.6	12.8	12.1
	40	23.0	23.1	22.4	22.0	21.5	21.2	20.6	19.7	19.3	18.8	18.1	17.5	17.0	15.9	15.5	15.0	14.1	13.6	12.7	11.9
	50	22.9	23.1	22.3	21.9	21.4	21.1	20.6	19.7	19.2	18.9	18.1	17.4	16.9	15.8	15.4	15.0	14.1	13.5	12.5	11.7
D	60	22.7	22.9	22.2	21.8	21.3	21.0	20.4	19.6	19.1	18.8	18.0	17.4	16.8	15.7	15.3	14.9	14.0	13.5	12.3	11.4
E	70	22.6	22.8	22.1	21.7	21.1	20.9	20.3	19.5	18.9	18.6	17.9	17.3	16.8	15.7	15.4	15.0	14.0	13.5	12.2	11.0
P	80	22.4	22.6	21.9	21.7	21.0	20.8	20.2	19.4	18.8	18.6	17.9	17.3	16.8	15.7	15.3	14.9	13.9	13.4	12.0	10.4
T	90	22.2	22.3	21.7	21.5	20.9	20.7	20.1	19.3	18.7	18.6	17.9	17.4	16.9	15.8	15.2	14.7	13.7	13.0	11.5	9.9
H	100	21.9	22.0	21.5	21.3	20.7	20.5	19.9	19.2	18.6	18.6	17.9	17.3	16.9	15.7	14.9	14.1	13.1	12.4	11.0	9.6
	120	21.3	21.5	21.0	20.7	20.1	19.9	19.3	18.6	18.1	18.1	17.7	16.7	16.5	14.9	13.6	13.0	11.9	11.2	10.3	9.2
(M)	150	19.9	20.1	19.8	19.6	18.6	18.6	18.0	17.3	16.9	16.7	15.9	15.5	15.0	13.1	12.2	11.3	10.5	10.1	9.3	8.7
	200	17.4	17.7	17.3	17.1	16.1	16.2	15.5	14.6	14.0	13.9	13.2	12.5	12.1	10.7	10.2	9.6	9.3	9.0	8.5	8.0
	250	14.5	14.7	14.7	14.3	13.4	13.4	12.9	12.3	12.0	11.6	11.2	10.9	10.5	9.6	9.2	8.6	8.3	8.2	7.8	7.5
	300	11.9	12.1	12.1	11.9	11.6	11.5	11.3	10.9	10.8	10.3	10.0	9.8	9.3	8.6	8.3	7.7	7.5	7.4	7.1	6.9
	400	8.7	8.9	8.9	9.0	8.9	8.9	8.8	8.6	8.5	8.2	7.9	7.7	7.4	6.7	6.6	6.2	6.2	6.1	6.2	6.1
	500	6.7	6.7	6.7	6.8	6.5	6.6	6.6	6.5	6.5	6.3	6.1	6.0	6.0	5.5	5.6	5.3	5.4	5.3	5.4	5.5
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

DISTANCE

MEAN XBT TEMPERATURE, DEG-C MID-MARCH

	0	23.4	23.2	22.7	22.2	21.6	21.2	20.5	19.7	19.1	18.7	17.9	17.3	16.8	15.8	15.4	14.8	14.1	13.5	12.9	12.2
	10	23.3	23.1	22.6	22.1	21.6	21.2	20.5	19.7	19.1	18.7	17.9	17.3	16.8	15.7	15.3	14.8	14.1	13.5	12.8	12.2
	20	23.2	23.1	22.6	22.1	21.5	21.1	20.5	19.6	19.1	18.7	17.9	17.2	16.7	15.7	15.3	14.8	14.1	13.4	12.7	12.2
	30	23.2	23.1	22.6	22.1	21.5	21.1	20.4	19.6	19.1	18.7	17.9	17.2	16.8	15.7	15.3	14.8	14.2	13.4	12.7	12.1
	40	23.1	23.1	22.5	22.0	21.4	21.1	20.4	19.6	19.1	18.7	18.0	17.2	16.8	15.7	15.3	14.8	14.2	13.4	12.6	11.9
	50	23.0	23.0	22.4	21.9	21.4	21.1	20.4	19.6	19.1	18.8	18.0	17.2	16.8	15.7	15.2	14.8	14.1	13.3	12.4	11.6
D	60	22.8	22.9	22.3	21.8	21.2	21.0	20.3	19.6	19.0	18.7	17.9	17.1	16.8	15.6	15.2	14.8	14.0	13.2	12.3	11.3
E	70	22.6	22.7	22.1	21.7	21.0	20.8	20.2	19.4	18.8	18.5	17.8	17.1	16.7	15.5	15.2	14.8	14.0	13.1	12.2	11.0
P	80	22.4	22.6	21.9	21.6	20.9	20.7	20.1	19.2	18.7	18.4	17.8	17.1	16.6	15.5	15.1	14.8	14.0	13.0	12.0	10.5
T	90	22.1	22.3	21.8	21.4	20.7	20.6	19.9	19.1	18.6	18.3	17.7	17.0	16.7	15.5	15.1	14.7	13.9	12.7	11.6	10.0
H	100	21.9	21.9	21.6	21.2	20.5	20.4	19.7	19.0	18.4	18.3	17.7	17.0	16.7	15.5	14.9	14.3	13.5	12.2	11.0	9.6
	120	21.3	21.5	21.1	20.8	19.9	19.8	19.1	18.5	18.0	18.0	17.5	16.6	16.5	14.9	13.9	13.3	12.4	11.0	10.2	9.2
(M)	150	20.0	20.1	20.0	19.6	18.6	18.6	18.0	17.3	16.8	16.8	15.9	15.5	15.1	13.2	12.1	11.5	10.8	10.0	9.3	8.7
	200	17.3	17.6	17.5	17.2	16.1	16.3	15.6	14.6	13.9	14.0	13.2	12.4	12.1	10.8	10.2	9.6	9.4	8.9	8.5	8.1
	250	14.4	14.7	14.8	14.3	13.4	13.5	12.9	12.2	11.8	11.7	11.3	10.8	10.5	9.6	9.2	8.7	8.4	8.1	7.8	7.5
	300	11.8	12.0	12.1	12.0	11.7	11.5	11.2	10.9	10.7	10.3	10.1	9.7	9.4	8.6	8.3	7.8	7.6	7.3	7.1	6.9
	400	8.7	8.9	8.9	9.1	8.9	8.9	8.7	8.6	8.4	8.2	7.9	7.6	7.5	6.7	6.6	6.3	6.2	6.2	6.2	6.0
	500	6.6	6.6	6.7	6.9	6.6	6.6	6.6	6.5	6.5	6.3	6.2	5.9	5.9	5.6	5.7	5.3	5.4	5.3	5.5	5.5
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

DISTANCE

MEAN XBT TEMPERATURE, DEG-C 01 APRIL

	0	23.5	23.2	22.8	22.3	21.7	21.2	20.5	19.9	19.1	18.7	17.8	17.1	16.7	15.7	15.3	14.9	14.2	13.4	12.8	12.1
	10	23.5	23.2	22.7	22.2	21.6	21.2	20.5	19.8	19.1	18.7	17.8	17.1	16.6	15.6	15.3	14.8	14.1	13.3	12.7	12.1
	20	23.4	23.2	22.7	22.2	21.6	21.1	20.4	19.8	19.1	18.7	17.8	17.1	16.6	15.6	15.2	14.8	14.2	13.3	12.7	12.0
	30	23.3	23.1	22.7	22.2	21.5	21.1	20.3	19.7	19.1	18.7	17.8	17.1	16.6	15.7	15.2	14.8	14.2	13.3	12.7	12.0
	40	23.2	23.1	22.6	22.1	21.4	21.1	20.3	19.7	19.1	18.7	17.9	17.1	16.7	15.7	15.2	14.8	14.2	13.3	12.6	11.8
	50	23.1	23.0	22.5	22.0	21.4	21.0	20.3	19.7	19.1	18.7	17.9	17.1	16.8	15.7	15.2	14.8	14.2	13.2	12.5	11.5
D	60	22.9	22.8	22.4	21.9	21.2	21.0	20.2	19.6	19.0	18.6	17.9	17.1	16.8	15.6	15.2	14.8	14.1	13.0	12.4	11.2
E	70	22.8	22.7	22.2	21.8	21.0	20.8	20.2	19.4	18.9	18.5	17.9	17.0	16.7	15.6	15.2	14.7	14.1	12.9	12.3	10.9
P	80	22.5	22.5	22.0	21.7	20.9	20.7	20.0	19.2	18.8	18.3	17.8	17.0	16.6	15.5	15.1	14.7	14.1	12.7	12.1	10.5
T	90	22.2	22.2	21.8	21.5	20.7	20.5	19.7	19.1	18.6	18.2	17.7	17.0	16.6	15.5	15.1	14.7	14.1	12.5	11.7	10.0
H	100	21.9	21.9	21.6	21.3	20.5	20.3	19.5	18.9	18.4	18.1	17.6	16.9	16.6	15.4	15.1	14.5	13.8	12.0	11.1	9.6
	120	21.4	21.4	21.1	20.8	19.9	19.7	18.9	18.4	17.9	17.9	17.4	16.7	16.5	15.0	14.2	13.6	12.8	10.9	10.2	9.2
(M)	150	20.0	20.0	20.0	19.7	18.7	18.6	18.0	17.3	16.8	16.8	15.9	15.6	15.2	13.3	12.2	11.7	11.1	9.8	9.3	8.8
	200	17.2	17.5	17.6	17.2	16.2	16.3	15.6	14.6	13.9	14.0	13.2	12.4	12.1	10.9	10.2	9.8	9.4	8.8	8.5	8.1
	250	14.2	14.6	14.8	14.4	13.5	13.4	12.9	12.2	11.8	11.7	11.3	10.8	10.6	9.7	9.2	8.8	8.5	8.1	7.8	7.5
	300	11.7	11.9	12.1	12.1	11.7	11.6	11.2	10.9	10.6	10.4	10.1	9.6	9.5	8.6	8.3	7.9	7.7	7.3	7.1	7.0
	400	8.6	8.8	8.9	9.2	8.9	8.9	8.7	8.6	8.3	8.2	8.0	7.5	7.5	6.8	6.6	6.5	6.4	6.2	6.2	6.1
	500	6.5	6.6	6.7	6.9	6.7	6.7	6.6	6.5	6.4	6.3	6.2	5.9	5.9	5.6	5.7	5.4	5.5	5.4	5.5	5.5
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

DISTANCE

MEAN XBT TEMPERATURE, DEG-C MID-APRIL

	0	23.7	23.4	23.0	22.5	21.9	21.4	20.6	20.2	19.4	18.9	17.9	17.2	16.7	15.9	15.5	15.0	14.3	13.4	12.8	12.0
	10	23.7	23.4	22.9	22.4	21.9	21.4	20.6	20.2	19.3	18.8	17.9	17.1	16.7	15.8	15.3	14.9	14.3	13.4	12.7	11.9
	20	23.6	23.3	22.9	22.4	21.8	21.3	20.5	20.1	19.3	18.8	17.9	17.1	16.6	15.8	15.2	14.9	14.3	13.3	12.7	11.8
	30	23.6	23.2	22.8	22.4	21.7	21.2	20.4	20.1	19.2	18.8	17.8	17.1	16.6	15.8	15.2	14.8	14.3	13.3	12.7	11.8
	40	23.4	23.2	22.7	22.3	21.6	21.1	20.3	20.0	19.2	18.7	17.9	17.1	16.6	15.8	15.2	14.8	14.3	13.3	12.7	11.6
	50	23.3	23.0	22.6	22.2	21.5	21.0	20.2	19.9	19.2	18.6	17.9	17.2	16.7	15.8	15.2	14.9	14.3	13.2	12.7	11.3
D	60	23.1	22.8	22.4	22.0	21.3	21.0	20.2	19.7	19.1	18.6	17.9	17.2	16.8	15.8	15.3	14.8	14.3	13.0	12.6	11.1
E	70	22.9	22.6	22.3	22.0	21.1	20.9	20.1	19.5	19.1	18.5	17.9	17.2	16.8	15.8	15.3	14.8	14.2	12.8	12.4	10.8
P	80	22.6	22.4	22.1	21.8	21.0	20.7	19.9	19.3	18.9	18.3	17.9	17.1	16.7	15.7	15.2	14.8	14.2	12.7	12.1	10.5
T	90	22.3	22.1	21.9	21.6	20.7	20.5	19.7	19.2	18.7	18.1	17.8	17.1	16.6	15.7	15.2	14.7	14.1	12.4	11.7	10.0
H	100	22.1	21.8	21.6	21.4	20.5	20.3	19.4	18.9	18.5	18.0	17.6	17.0	16.6	15.5	15.2	14.6	13.9	11.9	11.1	9.7
	120	21.4	21.2	20.9	20.9	19.8	19.6	18.7	18.4	17.9	17.7	17.3	16.8	16.4	15.2	14.5	13.9	13.0	10.7	10.1	9.2
(M)	150	19.9	19.9	19.8	19.8	18.7	18.4	17.9	17.3	16.8	16.7	15.9	15.8	15.2	13.5	12.5	11.8	11.2	9.7	9.4	8.8
	200	17.1	17.3	17.5	17.2	16.3	16.2	15.6	14.7	14.0	14.0	13.2	12.6	12.1	11.0	10.3	9.9	9.5	8.8	8.6	8.2
	250	14.1	14.5	14.6	14.5	13.7	13.3	12.9	12.3	11.8	11.7	11.4	10.8	10.5	9.8	9.3	9.0	8.6	8.1	7.9	7.6
	300	11.5	11.8	11.9	12.2	11.8	11.5	11.2	10.9	10.6	10.4	10.2	9.7	9.5	8.8	8.3	8.0	7.8	7.3	7.2	7.1
	400	8.5	8.8	8.9	9.2	9.0	8.9	8.7	8.6	8.3	8.2	8.0	7.6	7.5	6.9	6.6	6.6	6.5	6.3	6.2	6.2
	500	6.6	6.7	6.8	7.0	6.8	6.7	6.6	6.5	6.4	6.3	6.2	5.9	5.8	5.6	5.7	5.5	5.6	5.5	5.5	5.5
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

DISTANCE

MEAN XBT TEMPERATURE, DEG-C

01 MAY

	0	24.0	23.7	23.3	22.8	22.3	21.8	21.1	20.7	19.9	19.2	18.3	17.6	17.1	16.4	15.9	15.4	14.7	13.7	12.9	12.0
	10	24.0	23.7	23.2	22.8	22.3	21.7	21.0	20.7	19.8	19.2	18.2	17.5	17.0	16.3	15.7	15.3	14.6	13.6	12.9	11.9
	20	23.9	23.7	23.2	22.7	22.2	21.7	20.9	20.7	19.8	19.2	18.2	17.4	16.9	16.2	15.6	15.2	14.6	13.5	12.9	11.7
	30	23.9	23.5	23.0	22.6	22.0	21.5	20.8	20.5	19.7	19.1	18.0	17.4	16.8	16.1	15.4	15.0	14.4	13.4	12.8	11.6
	40	23.7	23.4	22.8	22.5	21.8	21.3	20.6	20.3	19.5	19.0	18.0	17.4	16.8	16.0	15.4	15.0	14.4	13.4	12.9	11.4
	50	23.5	23.1	22.6	22.4	21.6	21.1	20.4	20.1	19.4	18.8	18.0	17.4	16.8	16.0	15.4	15.0	14.3	13.3	12.8	11.2
D	60	23.2	22.8	22.5	22.3	21.5	21.0	20.2	19.8	19.3	18.7	18.0	17.4	16.8	16.0	15.4	14.9	14.3	13.1	12.7	10.9
E	70	23.0	22.6	22.2	22.1	21.3	20.8	20.1	19.6	19.2	18.6	18.0	17.4	16.9	16.0	15.5	14.9	14.3	13.0	12.4	10.7
P	80	22.7	22.3	22.0	21.9	21.1	20.6	19.9	19.5	19.1	18.4	18.0	17.4	16.8	16.0	15.4	14.8	14.2	12.7	12.1	10.4
T	90	22.4	22.1	21.8	21.8	20.8	20.4	19.6	19.3	18.8	18.2	17.9	17.3	16.7	15.9	15.3	14.7	14.0	12.4	11.7	10.0
H	100	22.1	21.8	21.4	21.5	20.5	20.2	19.3	19.0	18.5	18.1	17.7	17.2	16.7	15.7	15.3	14.6	13.9	11.8	11.1	9.7
	120	21.4	21.1	20.7	20.9	19.9	19.5	18.7	18.4	18.0	17.7	17.2	17.0	16.4	15.3	14.7	13.9	12.9	10.7	10.1	9.3
(M)	150	19.9	19.8	19.5	19.8	18.8	18.3	17.8	17.4	16.8	16.7	15.9	16.0	15.3	13.7	12.8	11.8	11.2	9.7	9.4	8.9
	200	17.1	17.3	17.2	17.4	16.4	15.9	15.6	14.8	14.2	14.0	13.1	12.8	12.1	11.1	10.5	9.9	9.5	8.7	8.6	8.3
	250	14.0	14.4	14.4	14.7	13.9	13.3	12.9	12.5	12.0	11.8	11.4	10.9	10.5	9.8	9.4	9.0	8.7	8.1	7.9	7.6
	300	11.4	11.8	11.8	12.3	11.9	11.5	11.3	11.0	10.7	10.5	10.2	9.8	9.5	8.9	8.4	8.1	7.8	7.4	7.2	7.2
	400	8.4	8.8	8.9	9.2	9.1	8.9	8.8	8.6	8.3	8.3	8.1	7.6	7.4	7.0	6.6	6.6	6.5	6.3	6.1	6.3
	500	6.6	6.7	6.8	7.0	7.0	6.8	6.7	6.6	6.4	6.3	6.2	5.9	5.8	5.6	5.6	5.5	5.7	5.6	5.4	5.6
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

DISTANCE

MEAN XBT TEMPERATURE, DEG-C

MID-MAY

	0	24.3	24.2	23.7	23.3	22.9	22.3	21.8	21.3	20.5	19.8	18.9	18.3	17.7	17.1	16.6	16.0	15.2	14.3	13.3	12.2
	10	24.3	24.2	23.7	23.2	22.8	22.3	21.7	21.3	20.5	19.8	18.8	18.2	17.6	17.0	16.4	15.8	15.1	14.1	13.2	12.0
	20	24.3	24.1	23.5	23.1	22.7	22.2	21.5	21.2	20.4	19.7	18.7	18.1	17.5	16.8	16.2	15.7	15.0	14.0	13.1	11.8
	30	24.2	24.0	23.3	23.0	22.5	22.0	21.4	21.0	20.3	19.6	18.5	17.9	17.3	16.6	15.9	15.5	14.8	13.8	13.1	11.7
	40	24.0	23.7	23.0	22.6	22.2	21.7	21.1	20.6	20.0	19.4	18.3	17.8	17.1	16.3	15.7	15.3	14.6	13.6	13.0	11.5
	50	23.7	23.4	22.7	22.6	21.9	21.3	20.7	20.3	19.8	19.2	18.2	17.7	17.0	16.2	15.6	15.1	14.4	13.5	12.8	11.1
D	60	23.4	23.1	22.4	22.5	21.7	21.1	20.4	19.9	19.5	19.0	18.1	17.7	16.9	16.2	15.6	15.0	14.4	13.3	12.5	10.7
E	70	23.0	22.7	22.2	22.2	21.5	20.8	20.1	19.7	19.3	18.8	18.0	17.6	16.9	16.2	15.6	14.9	14.3	13.2	12.2	10.5
P	80	22.7	22.4	21.9	22.0	21.2	20.6	19.9	19.5	19.1	18.6	18.0	17.6	16.9	16.1	15.5	14.8	14.1	12.9	11.8	10.2
T	90	22.5	22.1	21.6	21.8	20.9	20.4	19.7	19.3	18.9	18.4	17.9	17.5	16.8	16.0	15.3	14.6	13.9	12.4	11.4	10.0
H	100	22.1	21.8	21.2	21.5	20.6	20.1	19.4	19.0	18.6	18.2	17.7	17.4	16.7	15.8	15.2	14.4	13.6	11.9	11.0	9.7
	120	21.4	21.1	20.4	20.9	19.9	19.4	18.7	18.5	18.0	17.7	17.1	17.2	16.3	15.4	14.7	13.7	12.7	10.8	10.1	9.3
(M)	150	19.9	19.9	19.1	19.6	18.8	18.2	17.7	17.4	16.9	16.8	15.8	16.2	15.3	13.9	13.1	11.7	11.1	9.7	9.4	9.0
	200	17.2	17.4	16.8	17.5	16.5	15.8	15.5	15.0	14.4	14.1	13.0	13.0	12.1	11.1	10.6	9.8	9.5	8.8	8.6	8.3
	250	14.0	14.5	14.1	14.8	14.0	13.3	12.9	12.6	12.1	11.9	11.3	11.0	10.6	9.9	9.4	9.0	8.7	8.1	7.9	7.7
	300	11.4	12.0	11.8	12.4	12.0	11.5	11.4	11.1	10.8	10.6	10.2	9.9	9.5	8.9	8.4	8.1	7.8	7.4	7.2	7.2
	400	8.4	8.9	8.9	9.2	9.3	8.9	8.9	8.7	8.5	8.4	8.1	7.8	7.4	7.0	6.7	6.5	6.5	6.3	6.0	6.3
	500	6.7	6.7	6.9	7.0	7.0	6.8	6.8	6.7	6.5	6.4	6.2	6.0	5.8	5.7	5.5	5.6	5.7	5.6	5.4	5.6
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

DISTANCE

AN XBT TEMPERATURE, DEG-C

01 JUNE

0	24.7	24.6	24.1	23.7	23.4	22.9	22.4	21.9	21.2	20.5	19.6	19.1	18.5	17.9	17.3	16.6	15.9	14.9	13.8	12.6
10	24.6	24.6	24.1	23.6	23.3	22.8	22.3	21.8	21.1	20.4	19.5	19.0	18.4	17.8	17.1	16.5	15.8	14.8	13.6	12.4
20	24.6	24.5	23.9	23.5	23.2	22.7	22.2	21.7	21.1	20.3	19.4	18.9	18.2	17.5	16.9	16.3	15.6	14.6	13.5	12.2
30	24.5	24.3	23.6	23.3	22.9	22.5	22.0	21.5	20.9	20.1	19.1	18.5	17.9	17.1	16.5	16.0	15.3	14.2	13.4	12.0
40	24.3	24.1	23.3	23.1	22.6	22.1	21.6	21.0	20.4	19.9	18.7	18.2	17.6	16.7	16.1	15.7	15.0	14.0	13.1	11.6
50	23.9	23.7	22.9	22.8	22.3	21.6	21.1	20.5	20.1	19.6	18.6	18.0	17.3	16.5	15.9	15.3	14.6	13.8	12.7	11.1
60	23.5	23.3	22.5	22.5	21.9	21.2	20.6	20.1	19.7	19.2	18.3	17.9	17.1	16.3	15.8	15.1	14.4	13.6	12.3	10.6
70	23.1	23.0	22.1	22.2	21.6	20.9	20.3	19.8	19.4	19.0	18.1	17.7	17.0	16.3	15.7	14.9	14.2	13.4	11.9	10.4
80	22.7	22.6	21.7	21.9	21.2	20.6	20.0	19.5	19.1	18.7	18.0	17.7	16.9	16.2	15.5	14.7	14.0	12.9	11.5	10.1
90	22.4	22.2	21.4	21.7	20.9	20.3	19.7	19.3	18.9	18.5	17.8	17.6	16.9	16.0	15.3	14.5	13.7	12.5	11.1	9.9
100	22.1	21.9	21.1	21.4	20.6	20.0	19.5	19.0	18.6	18.3	17.6	17.5	16.7	15.9	15.2	14.2	13.4	11.9	10.7	9.7
120	21.3	21.2	20.3	20.8	20.0	19.4	18.8	18.5	18.1	17.8	17.1	17.2	16.3	15.4	14.6	13.4	12.4	10.9	10.0	9.4
150	19.9	20.1	19.0	19.8	18.9	18.3	17.8	17.5	17.0	16.9	15.8	16.2	15.2	14.0	13.1	11.6	11.0	9.8	9.3	9.0
200	17.4	17.6	16.6	17.5	16.6	15.8	15.5	15.1	14.5	14.3	12.8	13.1	12.2	11.2	10.6	9.8	9.5	8.8	8.5	8.3
250	14.1	14.7	14.0	14.9	14.0	13.4	13.0	12.7	12.3	12.1	11.3	11.1	10.6	9.9	9.4	8.9	8.7	8.1	7.8	7.7
300	11.5	12.1	11.8	12.4	12.0	11.6	11.5	11.2	10.9	10.7	10.2	10.0	9.5	9.0	8.4	8.0	7.8	7.4	7.1	7.1
400	8.4	8.9	9.0	9.2	9.3	8.9	9.0	8.8	8.6	8.5	8.1	7.9	7.4	7.0	6.7	6.5	6.5	6.3	6.0	6.2
500	6.8	6.7	6.9	6.9	6.9	6.8	6.8	6.7	6.7	6.5	6.1	6.1	5.9	5.7	5.5	5.5	5.7	5.5	5.3	5.6
N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

DISTANCE

AN XBT TEMPERATURE, DEG-C

MID-JUNE

0	25.0	25.0	24.5	24.1	23.9	23.4	23.0	22.4	21.9	21.2	20.5	20.0	19.5	18.8	18.2	17.5	16.7	15.8	14.5	13.2
10	25.0	24.9	24.5	24.0	23.8	23.4	23.0	22.3	21.8	21.1	20.3	19.9	19.3	18.7	18.1	17.3	16.6	15.6	14.3	13.0
20	24.9	24.8	24.3	23.9	23.7	23.3	22.8	22.2	21.8	21.1	20.2	19.7	19.0	18.4	17.8	17.0	16.3	15.3	14.1	12.8
30	24.9	24.7	24.0	23.7	23.4	23.1	22.6	21.9	21.5	20.8	19.9	19.3	18.7	17.7	17.3	16.6	16.0	14.9	13.8	12.5
40	24.6	24.5	23.6	23.4	23.1	22.6	22.1	21.3	21.0	20.4	19.4	18.7	18.2	17.1	16.6	16.0	15.4	14.5	13.3	11.9
50	24.1	24.1	23.1	23.0	22.6	21.9	21.5	20.7	20.4	20.0	19.0	18.3	17.7	16.7	16.2	15.4	14.9	14.1	12.7	11.2
60	23.6	23.7	22.6	22.6	22.1	21.4	20.9	20.2	19.9	19.5	18.6	18.0	17.3	16.5	16.0	15.1	14.5	13.8	12.1	10.6
70	23.2	23.3	22.1	22.2	21.6	21.0	20.5	19.8	19.5	19.1	18.3	17.8	17.1	16.3	15.7	14.8	14.2	13.4	11.6	10.3
80	22.8	22.8	21.7	21.8	21.2	20.6	20.1	19.5	19.2	18.8	18.0	17.7	16.9	16.1	15.5	14.5	13.8	13.0	11.2	10.0
90	22.4	22.5	21.3	21.5	20.9	20.3	19.8	19.2	18.9	18.6	17.8	17.6	16.8	16.0	15.3	14.3	13.6	12.5	10.8	9.8
100	22.0	22.1	21.0	21.2	20.5	20.0	19.6	18.9	18.6	18.3	17.6	17.4	16.7	15.9	15.1	14.0	13.2	12.0	10.5	9.7
120	21.2	21.3	20.3	20.6	19.9	19.4	19.0	18.4	18.1	17.9	17.0	17.2	16.3	15.4	14.5	13.2	12.3	11.0	9.9	9.3
150	19.9	20.2	19.0	19.6	18.8	18.4	17.9	17.5	17.1	17.0	15.8	16.2	15.2	14.1	13.0	11.5	10.9	10.0	9.3	8.9
200	17.4	17.8	16.6	17.4	16.5	15.9	15.5	15.1	14.5	14.5	12.8	13.1	12.3	11.3	10.6	9.7	9.5	8.9	8.5	8.3
250	14.2	14.8	14.0	14.8	13.9	13.5	13.0	12.7	12.4	12.2	11.2	11.2	10.7	10.0	9.4	8.8	8.6	8.2	7.8	7.6
300	11.6	12.2	11.8	12.3	12.0	11.6	11.5	11.2	11.0	10.8	10.2	10.0	9.5	9.0	8.5	8.0	7.8	7.4	7.1	7.1
400	8.4	9.0	9.0	9.1	9.3	8.9	9.0	8.8	8.7	8.6	8.1	7.9	7.5	7.0	6.8	6.4	6.4	6.3	6.1	6.1
500	6.8	6.7	6.8	6.8	6.8	6.9	6.9	6.8	6.8	6.6	6.1	6.1	6.0	5.8	5.5	5.5	5.7	5.5	5.4	5.6
N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

DISTANCE

MEAN XBT TEMPERATURE, DEG-C

01 JULY

	0	25.4	25.3	24.9	24.5	24.3	23.9	23.6	22.9	22.6	22.0	21.4	21.0	20.6	19.9	19.2	18.6	17.7	16.8	15.4	14.
	10	25.4	25.2	24.8	24.5	24.3	23.9	23.5	22.8	22.5	21.9	21.3	20.9	20.4	19.7	19.1	18.4	17.6	16.6	15.2	13.9
	20	25.3	25.2	24.7	24.4	24.2	23.8	23.4	22.7	22.4	21.8	21.2	20.7	20.1	19.4	18.8	18.0	17.3	16.2	14.9	13.
	30	25.3	25.1	24.5	24.1	24.0	23.6	23.2	22.4	22.2	21.6	20.9	20.1	19.7	18.5	18.1	17.5	17.0	15.7	14.6	13.
	40	25.0	24.8	24.1	23.8	23.5	23.1	22.6	21.8	21.6	21.1	20.2	19.2	18.8	17.6	17.1	16.4	16.0	15.1	13.7	12.2
	50	24.4	24.4	23.5	23.2	22.9	22.3	21.9	21.1	20.8	20.3	19.5	18.6	18.0	17.0	16.5	15.7	15.2	14.5	12.9	11.
D	60	23.8	24.0	22.8	22.6	22.2	21.6	21.2	20.4	20.2	19.7	19.0	18.2	17.6	16.7	16.2	15.2	14.7	13.9	12.2	10.
E	70	23.4	23.5	22.3	22.1	21.6	21.1	20.7	19.9	19.7	19.3	18.5	17.9	17.2	16.4	15.8	14.8	14.2	13.4	11.5	10.3
P	80	22.9	23.1	21.8	21.7	21.1	20.7	20.3	19.5	19.3	18.9	18.2	17.7	16.9	16.1	15.5	14.5	13.8	12.9	11.0	10.
T	90	22.4	22.7	21.4	21.3	20.7	20.4	19.9	19.1	19.0	18.6	17.9	17.5	16.7	16.0	15.3	14.2	13.5	12.4	10.7	9.
H	100	22.0	22.2	21.1	21.0	20.4	20.1	19.6	18.8	18.7	18.3	17.7	17.3	16.6	15.8	15.1	13.9	13.2	12.0	10.4	9.6
	120	21.2	21.4	20.4	20.4	19.8	19.5	19.1	18.4	18.2	18.0	17.1	17.0	16.3	15.4	14.4	13.1	12.3	11.1	9.9	9.
(M)	150	20.0	20.3	19.2	19.4	18.8	18.6	18.0	17.4	17.2	17.1	15.9	16.0	15.1	14.2	12.9	11.6	10.9	10.1	9.2	8.
	200	17.5	17.9	16.8	17.1	16.5	16.1	15.5	15.1	14.6	14.6	12.9	13.1	12.3	11.5	10.5	9.8	9.5	9.0	8.5	8.2
	250	14.3	14.8	14.1	14.4	13.7	13.7	13.0	12.7	12.4	12.3	11.3	11.2	10.7	10.2	9.4	8.8	8.7	8.3	7.8	7.
	300	11.6	12.2	11.9	12.1	11.9	11.7	11.5	11.1	11.0	10.9	10.2	10.0	9.6	9.0	8.4	8.0	7.8	7.5	7.2	7.
	400	8.5	8.9	8.9	9.0	9.2	9.0	9.0	8.8	8.7	8.7	8.2	8.0	7.6	7.1	6.8	6.5	6.4	6.3	6.2	6.0
	500	6.7	6.6	6.7	6.7	6.6	7.0	6.9	6.8	6.9	6.6	6.2	6.2	6.0	5.8	5.7	5.5	5.5	5.5	5.5	5.
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	195
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

DISTANCE

MEAN XBT TEMPERATURE, DEG-C

MID-JUL

	0	25.7	25.4	25.1	24.8	24.6	24.3	24.0	23.4	23.0	22.6	22.1	21.7	21.3	20.6	20.0	19.4	18.5	17.5	16.2	14.7
	10	25.7	25.4	25.1	24.8	24.6	24.2	23.9	23.3	23.0	22.5	22.0	21.6	21.1	20.5	19.8	19.2	18.4	17.3	15.9	14.
	20	25.6	25.3	25.0	24.7	24.5	24.1	23.8	23.1	22.9	22.4	21.9	21.3	20.8	20.2	19.6	18.8	18.1	17.0	15.6	14.
	30	25.6	25.3	24.8	24.5	24.3	24.0	23.6	22.8	22.7	22.2	21.6	20.7	20.4	19.2	18.8	18.1	17.7	16.5	15.3	13.4
	40	25.4	25.1	24.5	24.2	23.8	23.5	23.0	22.2	22.0	21.6	20.8	19.7	19.2	18.1	17.5	16.8	16.5	15.6	14.3	12.
	50	24.8	24.7	23.9	23.5	23.1	22.6	22.2	21.5	21.1	20.5	19.8	18.8	18.3	17.3	16.7	15.9	15.5	14.8	13.4	11.
D	60	24.1	24.2	23.1	22.7	22.2	21.8	21.5	20.7	20.4	19.8	19.3	18.4	17.7	16.9	16.3	15.4	14.9	14.0	12.6	10.8
E	70	23.5	23.6	22.5	22.2	21.6	21.3	20.9	20.0	19.9	19.3	18.8	18.0	17.3	16.5	15.9	14.9	14.4	13.4	11.8	10.
P	80	23.0	23.1	22.0	21.7	21.1	20.9	20.4	19.5	19.5	18.9	18.4	17.7	16.9	16.2	15.6	14.5	13.8	12.8	11.2	10.
T	90	22.5	22.7	21.6	21.3	20.7	20.5	20.0	19.1	19.1	18.5	18.1	17.5	16.7	16.0	15.3	14.3	13.5	12.3	10.8	9.8
H	100	22.1	22.2	21.2	20.9	20.3	20.2	19.6	18.8	18.8	18.2	17.8	17.3	16.6	15.9	15.1	13.9	13.2	11.9	10.5	9
	120	21.2	21.4	20.5	20.2	19.7	19.6	19.1	18.3	18.3	17.9	17.2	17.0	16.3	15.5	14.5	13.2	12.4	11.2	10.0	9
(M)	150	20.0	20.2	19.4	19.2	18.7	18.7	18.1	17.4	17.3	17.0	16.1	15.9	15.1	14.2	12.8	11.8	11.0	10.1	9.3	8.8
	200	17.4	17.8	16.9	16.8	16.4	16.3	15.6	15.0	14.6	14.6	13.1	13.1	12.3	11.7	10.5	9.9	9.5	9.1	8.6	8
	250	14.3	14.7	14.1	14.0	13.6	13.8	13.1	12.6	12.4	12.3	11.4	11.2	10.7	10.3	9.4	8.9	8.7	8.3	7.9	7
	300	11.7	12.0	11.9	11.8	11.8	11.8	11.4	11.1	11.0	10.9	10.3	10.0	9.6	9.1	8.4	8.1	7.8	7.5	7.3	6.9
	400	8.6	8.9	8.8	8.9	9.0	9.1	9.0	8.8	8.7	8.7	8.2	8.0	7.6	7.2	6.8	6.5	6.4	6.4	6.3	6
	500	6.7	6.6	6.6	6.6	6.6	7.1	6.9	6.8	6.8	6.6	6.3	6.2	6.1	5.8	5.8	5.5	5.5	5.5	5.6	5
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	36

DISTANCE

MEAN XBT TEMPERATURE, DEG-C

01 AUGUST

	0	25.9	25.6	25.2	25.1	24.9	24.5	24.2	23.8	23.5	23.1	22.7	22.2	22.0	21.3	20.6	20.2	19.3	18.1	16.9	15.3
	10	25.9	25.6	25.3	25.1	24.9	24.5	24.2	23.8	23.4	23.0	22.6	22.1	21.8	21.2	20.5	20.0	19.1	17.9	16.7	15.1
	20	25.9	25.5	25.2	25.0	24.8	24.4	24.1	23.6	23.3	22.9	22.5	21.9	21.5	20.9	20.3	19.6	18.9	17.7	16.4	14.6
	30	25.9	25.5	25.1	24.9	24.7	24.3	23.9	23.3	23.1	22.7	22.2	21.4	20.9	20.0	19.4	18.8	18.3	17.2	16.1	13.7
	40	25.7	25.3	24.9	24.6	24.2	23.9	23.3	22.7	22.5	22.0	21.4	20.2	19.6	18.7	18.1	17.2	17.0	16.2	15.1	12.5
	50	25.2	24.9	24.3	23.8	23.3	22.9	22.5	21.9	21.5	20.7	20.2	19.2	18.5	17.6	17.0	16.1	15.8	15.0	14.0	11.5
D	60	24.5	24.3	23.5	23.0	22.3	22.1	21.6	20.9	20.6	19.8	19.5	18.7	17.8	17.0	16.5	15.6	15.1	14.1	13.2	11.0
E	70	23.7	23.6	22.8	22.3	21.6	21.5	21.0	20.2	20.1	19.3	18.9	18.2	17.4	16.7	16.1	15.1	14.5	13.4	12.3	10.4
P	80	23.1	23.1	22.3	21.8	21.1	21.0	20.5	19.7	19.7	18.8	18.6	17.9	17.0	16.3	15.8	14.7	13.9	12.8	11.6	10.1
T	90	22.7	22.6	21.8	21.3	20.7	20.6	20.0	19.3	19.3	18.5	18.3	17.6	16.7	16.1	15.5	14.4	13.6	12.3	11.2	9.9
H	100	22.2	22.2	21.4	20.9	20.3	20.2	19.6	18.9	19.0	18.2	18.0	17.4	16.6	15.9	15.3	14.1	13.3	11.9	10.8	9.6
	120	21.4	21.2	20.6	20.1	19.7	19.6	19.0	18.3	18.3	17.8	17.4	17.0	16.3	15.6	14.6	13.4	12.5	11.2	10.3	9.2
(M)	150	20.1	20.0	19.5	19.0	18.6	18.7	18.1	17.4	17.4	16.9	16.3	16.0	15.1	14.3	12.8	12.0	11.0	10.1	9.5	8.8
	200	17.5	17.6	17.1	16.5	16.3	16.4	15.6	14.9	14.7	14.4	13.4	13.1	12.2	11.8	10.5	10.1	9.5	9.1	8.8	8.2
	250	14.4	14.5	14.2	13.7	13.6	13.8	13.1	12.5	12.4	12.2	11.5	11.2	10.7	10.3	9.4	9.1	8.7	8.4	8.0	7.5
	300	11.8	11.8	11.8	11.6	11.7	11.8	11.3	11.0	10.9	10.8	10.3	10.0	9.6	9.2	8.5	8.2	7.8	7.6	7.4	6.9
	400	8.7	8.7	8.7	8.9	8.9	9.1	8.9	8.7	8.6	8.6	8.2	8.0	7.6	7.3	6.8	6.6	6.4	6.4	6.4	6.1
	500	6.6	6.6	6.6	6.6	6.6	7.2	6.9	6.7	6.8	6.6	6.3	6.2	6.0	5.8	5.8	5.6	5.4	5.5	5.7	5.6
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

DISTANCE

MEAN XBT TEMPERATURE, DEG-C

MID-AUGUST

	0	26.2	25.8	25.5	25.4	25.2	24.8	24.5	24.3	23.8	23.5	23.1	22.6	22.4	21.9	21.1	20.7	19.8	18.6	17.5	15.8
	10	26.2	25.7	25.5	25.4	25.1	24.8	24.5	24.2	23.7	23.5	23.1	22.5	22.2	21.8	21.0	20.5	19.7	18.4	17.3	15.6
	20	26.2	25.7	25.5	25.3	25.1	24.7	24.4	24.1	23.6	23.4	23.0	22.4	21.9	21.5	20.8	20.1	19.4	18.2	17.1	14.9
	30	26.1	25.7	25.4	25.3	25.0	24.6	24.2	23.9	23.5	23.2	22.7	21.9	21.4	20.7	20.0	19.4	18.8	17.9	16.7	13.8
	40	26.0	25.6	25.3	25.1	24.5	24.2	23.7	23.3	23.0	22.5	21.9	20.9	19.9	19.4	18.7	17.8	17.4	16.6	15.8	12.5
	50	25.5	25.1	24.7	24.3	23.5	23.3	22.8	22.4	21.9	20.9	20.5	19.8	18.7	17.9	17.3	16.5	16.0	15.3	14.7	11.5
D	60	24.8	24.4	23.8	23.3	22.5	22.3	21.8	21.3	20.9	19.8	19.6	19.0	17.9	17.2	16.6	15.8	15.2	14.2	13.8	11.1
E	70	23.9	23.6	23.0	22.6	21.7	21.6	21.0	20.5	20.3	19.2	19.0	18.5	17.4	16.8	16.2	15.3	14.6	13.5	12.9	10.4
P	80	23.3	22.9	22.4	22.0	21.2	21.1	20.5	19.9	19.8	18.8	18.7	18.1	17.1	16.5	15.9	14.9	14.0	12.9	12.1	10.1
T	90	22.9	22.4	21.9	21.5	20.8	20.6	20.0	19.5	19.4	18.5	18.4	17.8	16.8	16.3	15.6	14.6	13.6	12.4	11.6	9.9
H	100	22.4	22.0	21.5	21.0	20.3	20.3	19.6	19.1	19.1	18.2	18.1	17.5	16.6	16.1	15.4	14.3	13.3	12.0	11.2	9.6
	120	21.5	21.0	20.6	20.1	19.6	19.6	19.0	18.4	18.4	17.6	17.5	17.1	16.3	15.6	14.8	13.6	12.6	11.2	10.5	9.2
(M)	150	20.2	19.8	19.5	18.9	18.6	18.6	18.0	17.4	17.4	16.7	16.5	16.1	15.0	14.3	13.0	12.2	11.0	10.1	9.7	8.8
	200	17.5	17.3	17.1	16.4	16.3	16.3	15.7	14.9	14.7	14.1	13.7	13.2	12.2	11.8	10.6	10.2	9.4	9.1	9.0	8.2
	250	14.5	14.3	14.2	13.5	13.7	13.6	13.1	12.5	12.3	12.0	11.6	11.2	10.7	10.3	9.4	9.2	8.7	8.4	8.2	7.5
	300	11.9	11.6	11.7	11.5	11.8	11.7	11.3	11.0	10.9	10.7	10.4	10.1	9.6	9.2	8.5	8.2	7.8	7.6	7.5	6.9
	400	8.8	8.6	8.7	8.9	8.9	9.1	8.9	8.7	8.6	8.5	8.2	8.0	7.6	7.3	6.8	6.7	6.4	6.5	6.4	6.2
	500	6.7	6.7	6.6	6.6	6.6	7.2	6.9	6.7	6.7	6.5	6.4	6.1	6.0	5.7	5.8	5.6	5.4	5.6	5.7	5.7
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

DISTANCE

MEAN XBT TEMPERATURE, DEG-C

01 SEPTEMBER

	0	26.3	26.0	25.7	25.7	25.4	25.1	24.8	24.6	24.1	23.8	23.4	22.9	22.6	22.2	21.4	20.9	20.1	18.8	17.8	16.1
	10	26.4	26.0	25.7	25.6	25.4	25.1	24.7	24.5	24.0	23.8	23.3	22.8	22.5	22.1	21.3	20.7	20.0	18.7	17.7	15.8
	20	26.3	25.9	25.7	25.6	25.3	25.0	24.6	24.4	23.9	23.7	23.3	22.7	22.3	21.9	21.1	20.4	19.7	18.6	17.5	15.0
	30	26.3	25.9	25.7	25.6	25.2	24.9	24.5	24.3	23.8	23.5	22.9	22.4	21.7	21.3	20.5	19.8	19.1	18.3	17.2	13.9
	40	26.2	25.8	25.5	25.4	24.8	24.6	24.0	23.4	23.4	22.9	22.2	21.5	20.4	20.0	19.3	18.4	17.7	17.1	16.4	12.5
	50	25.8	25.3	25.1	24.7	23.9	23.7	23.1	22.8	22.3	21.3	20.8	20.4	19.0	18.3	17.7	16.9	16.2	15.6	15.2	11.5
D	60	25.1	24.5	24.2	23.6	22.8	22.[illegible]	21.9	21.6	21.1	20.1	19.7	19.4	18.0	17.3	16.7	15.9	15.2	14.4	14.2	11.0
E	70	24.1	23.6	23.3	22.9	21.9	21.7	21.0	20.7	20.3	19.2	19.0	18.7	17.5	16.8	16.3	15.4	14.6	13.6	13.3	10.5
P	80	23.4	22.9	22.5	22.2	21.4	21.1	20.4	20.1	19.8	18.8	18.7	18.3	17.1	16.6	16.0	15.1	14.0	13.0	12.4	10.1
T	90	23.1	22.3	22.0	21.6	20.9	20.6	20.0	19.7	19.4	18.5	18.4	18.0	16.9	16.4	15.7	14.7	13.6	12.5	11.9	9.9
H	100	22.5	21.9	21.5	21.2	20.4	20.2	19.6	19.3	19.0	18.2	18.1	17.8	16.7	16.2	15.5	14.4	13.2	12.0	11.4	9.6
	120	21.6	20.9	20.6	20.2	19.7	19.5	18.9	18.5	18.3	17.5	17.6	17.2	16.2	15.6	14.9	13.7	12.5	11.3	10.7	9.2
(M)	150	20.2	19.6	19.3	19.0	18.6	18.4	18.0	17.5	17.3	16.6	16.5	16.1	15.0	14.2	13.2	12.1	10.9	10.1	9.8	8.8
	200	17.7	17.2	17.0	16.5	16.4	16.1	15.8	15.0	14.7	13.9	13.9	13.3	12.1	11.6	10.7	10.2	9.4	9.1	9.0	8.2
	250	14.7	14.2	14.1	13.6	13.9	13.5	13.2	12.6	12.3	11.8	11.7	11.2	10.6	10.2	9.5	9.2	8.6	8.4	8.3	7.5
	300	12.0	11.6	11.6	11.6	11.9	11.6	11.4	11.1	10.9	10.6	10.4	10.1	9.5	9.2	8.5	8.2	7.7	7.7	7.5	7.0
	400	8.9	8.6	8.6	8.9	9.0	9.1	8.9	8.7	8.6	8.3	8.2	8.0	7.5	7.2	6.8	6.6	6.4	6.5	6.4	6.3
	500	6.7	6.7	6.6	6.7	6.7	7.1	6.8	6.7	6.6	6.5	6.4	6.1	5.9	5.6	5.7	5.6	5.5	5.6	5.7	5.7
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

DISTANCE

MEAN XBT TEMPERATURE, DEG-C

MID-SEPTEMBER

	0	26.4	26.2	25.9	25.9	25.6	25.3	25.0	24.7	24.2	23.9	23.4	23.0	22.5	22.2	21.5	20.7	20.1	18.9	17.8	16.2
	10	26.5	26.2	25.9	25.8	25.6	25.3	24.9	24.7	24.2	23.9	23.4	23.0	22.5	22.1	21.4	20.6	20.0	18.8	17.8	15.9
	20	26.4	26.1	25.9	25.8	25.6	25.3	24.8	24.6	24.1	23.8	23.3	22.9	22.4	22.0	21.3	20.4	19.8	18.7	17.6	15.2
	30	26.4	26.1	25.9	25.7	25.5	25.2	24.7	24.5	24.0	23.7	23.0	22.7	21.9	21.6	20.8	19.9	19.2	18.5	17.4	14.0
	40	26.3	26.0	25.7	25.6	25.1	24.9	24.4	24.1	23.7	23.2	22.4	22.0	20.8	20.5	19.8	19.0	18.0	17.4	16.6	12.6
	50	26.0	25.5	25.3	25.1	24.2	24.2	23.6	23.2	22.7	21.8	21.1	21.0	19.4	18.7	18.1	17.3	16.5	15.9	15.3	11.5
D	60	25.4	24.8	24.5	24.3	23.2	23.0	22.2	22.0	21.4	20.5	19.9	19.8	18.2	17.5	16.9	16.1	15.2	14.7	14.2	11.0
E	70	24.4	23.8	23.5	23.2	22.3	21.9	21.1	21.1	20.4	19.4	19.0	19.0	17.5	16.9	16.3	15.4	14.5	13.8	13.3	10.4
P	80	23.6	23.0	22.6	22.4	21.6	21.1	20.4	20.4	19.7	18.8	18.6	18.4	17.2	16.6	16.0	15.1	13.9	13.1	12.5	10.1
T	90	23.2	22.4	21.9	21.8	21.0	20.6	20.1	19.9	19.3	18.5	18.3	18.1	16.9	16.4	15.7	14.7	13.5	12.6	12.0	9.9
H	100	22.6	21.9	21.4	21.3	20.5	20.2	19.7	19.5	18.9	18.2	18.0	17.9	16.7	16.2	15.5	14.4	13.1	12.1	11.5	9.6
	120	21.6	20.9	20.5	20.4	19.7	19.4	18.9	18.7	18.2	17.5	17.5	17.3	16.2	15.5	14.9	13.5	12.3	11.3	10.7	9.2
(M)	150	20.3	19.6	19.2	19.1	18.6	18.3	17.9	17.6	17.2	16.4	16.4	16.1	14.9	14.0	13.4	11.9	10.7	10.1	9.8	8.7
	200	17.8	17.1	16.9	16.8	16.4	15.9	15.8	15.1	14.7	13.7	13.8	13.3	12.1	11.4	10.8	10.1	9.3	9.1	9.0	8.1
	250	14.9	14.1	14.0	13.9	14.0	13.4	13.3	12.7	12.3	11.7	11.6	11.2	10.6	10.0	9.5	9.2	8.5	8.3	8.3	7.5
	300	12.1	11.7	11.6	11.8	11.9	11.5	11.5	11.2	10.9	10.4	10.4	10.1	9.5	9.1	8.6	8.1	7.6	7.6	7.5	7.0
	400	9.0	8.6	8.7	9.0	9.1	9.0	8.9	8.8	8.6	8.2	8.2	7.9	7.5	7.1	6.8	6.5	6.3	6.5	6.3	6.3
	500	6.8	6.7	6.7	6.9	6.8	7.0	6.8	6.7	6.5	6.4	6.3	6.1	5.9	5.6	5.6	5.6	5.5	5.5	5.6	5.7
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

DISTANCE

MEAN XBT TEMPERATURE, DEG-C

01 OCTOB

	0	26.4	26.2	26.1	25.9	25.7	25.4	25.0	24.6	24.2	23.8	23.2	22.9	22.3	21.9	21.3	20.3	19.9	18.7	17.6
	10	26.4	26.2	26.0	25.8	25.7	25.4	25.0	24.6	24.1	23.8	23.2	22.9	22.3	21.9	21.2	20.2	19.7	18.6	17.5
	20	26.4	26.2	26.0	25.8	25.6	25.4	24.9	24.5	24.1	23.8	23.1	22.8	22.3	21.8	21.1	20.1	19.6	18.6	17.4
	30	26.4	26.2	25.9	25.7	25.6	25.3	24.8	24.5	24.1	23.7	22.9	22.7	21.9	21.5	20.9	19.9	19.1	18.4	17.2
	40	26.3	26.1	25.8	25.6	25.3	25.1	24.6	24.2	23.8	23.3	22.4	22.3	21.2	20.7	20.1	19.3	18.2	17.6	16.4
	50	26.1	25.7	25.5	25.3	24.6	24.5	23.9	23.4	23.0	22.3	21.3	21.4	19.9	19.1	18.6	17.6	16.8	16.3	15.1
D	60	25.6	25.1	24.7	24.6	23.7	23.4	22.5	22.4	21.7	21.0	20.0	20.2	18.5	17.7	17.1	16.2	15.3	15.0	14.0
E	70	24.6	24.2	23.6	23.5	22.6	22.0	21.4	21.4	20.4	19.7	19.0	19.2	17.6	16.9	16.3	15.4	14.4	13.9	13.0
P	80	23.7	23.3	22.7	22.6	21.7	21.2	20.6	20.6	19.6	18.9	18.5	18.5	17.1	16.6	15.9	14.9	13.8	13.2	12.2
T	90	23.2	22.6	22.0	21.9	21.1	20.6	20.1	20.0	19.1	18.5	18.1	18.1	16.9	16.3	15.6	14.5	13.4	12.7	11.7
H	100	22.6	22.1	21.4	21.4	20.6	20.1	19.7	19.6	18.7	18.1	17.8	17.9	16.7	16.1	15.4	14.1	13.0	12.1	11.2
	120	21.6	21.1	20.5	20.5	19.8	19.3	19.0	18.8	18.1	17.5	17.3	17.2	16.1	15.4	14.7	13.2	12.0	11.3	10.6
(M)	150	20.3	19.8	19.2	19.3	18.6	18.2	17.9	17.7	17.1	16.4	16.2	16.0	14.8	13.8	13.4	11.5	10.6	10.1	9.7
	200	17.9	17.2	16.8	17.0	16.4	15.8	15.8	15.3	14.5	13.7	13.6	13.1	12.1	11.2	10.8	9.9	9.3	9.0	8.8
	250	14.9	14.2	14.0	14.2	14.1	13.4	13.3	12.9	12.3	11.6	11.5	11.2	10.5	9.9	9.5	9.0	8.5	8.3	8.1
	300	12.2	11.8	11.7	11.9	11.9	11.5	11.5	11.2	10.9	10.4	10.3	10.0	9.5	8.9	8.6	7.9	7.6	7.6	7.4
	400	8.9	8.6	8.7	9.1	9.2	9.0	8.9	8.8	8.7	8.2	8.1	7.8	7.5	7.0	6.8	6.4	6.3	6.4	6.3
	500	6.9	6.7	6.8	6.9	6.8	6.9	6.8	6.8	6.5	6.4	6.2	6.1	6.0	5.6	5.6	5.5	5.5	5.5	5.5
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428

DISTANCE

MEAN XBT TEMPERATURE, DEG-C

MID-OCTOB

	0	26.3	26.1	26.0	25.7	25.5	25.3	24.8	24.3	23.9	23.5	22.8	22.5	21.9	21.4	20.8	19.7	19.3	18.3	17.0
	10	26.3	26.1	25.9	25.7	25.5	25.3	24.8	24.2	23.9	23.4	22.8	22.5	21.9	21.3	20.7	19.6	19.2	18.3	17.0
	20	26.3	26.1	25.9	25.6	25.5	25.3	24.7	24.2	23.9	23.4	22.7	22.5	21.9	21.3	20.7	19.6	19.1	18.2	16.9
	30	26.2	26.1	25.8	25.5	25.5	25.2	24.7	24.2	23.9	23.4	22.6	22.5	21.7	21.2	20.6	19.5	18.9	18.1	16.7
	40	26.2	26.0	25.7	25.4	25.3	25.1	24.6	24.0	23.7	23.2	22.3	22.2	21.3	20.7	20.1	19.3	18.3	17.6	16.0
	50	26.0	25.8	25.5	25.2	24.8	24.7	24.1	23.4	23.1	22.6	21.4	21.5	20.3	19.4	18.8	17.8	17.0	16.5	14.8
D	60	25.6	25.3	24.8	24.7	24.0	23.7	22.9	22.7	21.9	21.4	20.3	20.4	18.9	17.9	17.3	16.3	15.6	15.2	13.5
E	70	24.9	24.6	23.8	23.7	22.9	22.3	21.8	21.7	20.6	20.0	19.2	19.3	17.8	17.1	16.3	15.2	14.4	13.9	12.6
P	80	24.0	23.8	22.8	22.8	21.9	21.3	20.9	20.7	19.7	19.1	18.5	18.5	17.2	16.6	15.8	14.6	13.8	13.1	11.8
T	90	23.3	23.0	22.1	22.0	21.2	20.7	20.3	20.1	19.1	18.5	18.1	18.1	16.8	16.3	15.5	14.3	13.4	12.6	11.3
H	100	22.5	22.3	21.5	21.4	20.6	20.1	19.8	19.7	18.7	18.1	17.7	17.8	16.6	16.0	15.2	13.8	12.9	12.0	10.9
	120	21.6	21.3	20.7	20.6	19.8	19.3	19.0	18.9	18.0	17.5	17.1	17.1	16.1	15.3	14.5	12.9	11.9	11.2	10.3
(M)	150	20.3	19.9	19.4	19.4	18.7	18.2	17.9	17.8	17.0	16.4	16.0	15.8	14.8	13.7	13.3	11.2	10.5	10.1	9.5
	200	17.9	17.3	17.0	17.2	16.4	15.8	15.8	15.5	14.4	13.7	13.3	12.9	12.1	11.1	10.8	9.7	9.3	9.0	8.6
	250	14.8	14.3	14.2	14.4	14.0	13.4	13.3	13.0	12.3	11.7	11.4	11.1	10.6	9.8	9.5	8.9	8.4	8.2	7.9
	300	12.1	11.9	11.8	12.1	11.8	11.5	11.5	11.3	10.9	10.4	10.2	9.9	9.5	8.9	8.6	7.8	7.6	7.5	7.3
	400	8.8	8.7	8.7	9.1	9.2	8.9	8.9	8.8	8.7	8.2	8.1	7.7	7.5	7.0	6.8	6.3	6.3	6.3	6.3
	500	6.8	6.7	6.8	6.9	6.8	6.8	6.8	6.8	6.6	6.3	6.2	6.0	6.0	5.6	5.6	5.5	5.5	5.5	5.4
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428

DISTANCE

MEAN XBT TEMPERATURE, DEG-C

01 NOVEMBER

	0	26.0	25.8	25.6	25.3	25.2	24.9	24.4	23.8	23.5	22.9	22.2	21.9	21.3	20.6	20.1	19.0	18.6	17.7	16.3	15.1
	10	26.0	25.8	25.6	25.3	25.1	24.9	24.4	23.8	23.5	22.8	22.2	21.9	21.3	20.6	20.0	19.0	18.6	17.7	16.3	15.0
	20	26.0	25.8	25.6	25.3	25.1	24.9	24.4	23.7	23.5	22.8	22.2	21.9	21.3	20.6	20.0	19.0	18.6	17.7	16.2	14.8
	30	25.9	25.8	25.6	25.2	25.1	24.9	24.4	23.7	23.4	22.8	22.1	21.9	21.3	20.6	20.0	19.0	18.5	17.6	16.1	14.1
	40	25.9	25.7	25.5	25.1	25.0	24.8	24.4	23.7	23.4	22.8	22.0	21.8	21.1	20.4	19.7	19.0	18.2	17.4	15.4	13.1
	50	25.8	25.6	25.3	25.0	24.8	24.6	24.0	23.3	23.0	22.5	21.4	21.4	20.4	19.5	18.9	17.9	17.2	16.6	14.5	11.7
D	60	25.5	25.4	24.7	24.6	24.2	23.8	23.1	22.8	22.1	21.6	20.4	20.4	19.3	18.2	17.6	16.3	15.8	15.4	13.2	10.7
E	70	25.1	24.9	23.9	23.8	23.1	22.5	22.3	21.9	20.9	20.3	19.4	19.3	18.1	17.4	16.4	15.1	14.7	13.9	12.2	10.2
P	80	24.2	24.2	23.1	22.9	22.0	21.6	21.3	20.9	20.0	19.3	18.7	18.5	17.3	16.7	15.7	14.5	13.9	13.1	11.4	9.9
T	90	23.4	23.4	22.4	22.1	21.2	20.8	20.4	20.3	19.3	18.6	18.2	18.0	16.8	16.3	15.4	14.0	13.3	12.4	10.9	9.7
H	100	22.6	22.6	21.8	21.5	20.7	20.3	19.9	19.7	18.7	18.1	17.7	17.6	16.5	15.9	15.1	13.5	12.8	11.9	10.5	9.4
	120	21.6	21.4	20.9	20.6	19.8	19.4	19.1	18.9	18.0	17.5	17.0	16.9	16.0	15.3	14.4	12.6	11.9	11.1	10.0	9.1
M)	150	20.2	20.1	19.7	19.4	18.6	18.2	18.0	17.8	16.9	16.3	15.9	15.6	14.7	13.7	13.1	11.1	10.6	10.0	9.3	8.6
	200	17.7	17.4	17.3	17.1	16.3	15.8	15.7	15.6	14.2	13.8	13.0	12.7	12.1	11.1	10.7	9.6	9.3	9.0	8.5	7.9
	250	14.6	14.3	14.4	14.3	13.8	13.4	13.2	13.0	12.2	11.7	11.3	11.0	10.6	9.8	9.5	8.8	8.5	8.2	7.8	7.3
	300	11.9	11.9	11.9	12.0	11.7	11.5	11.4	11.3	10.9	10.5	10.1	9.8	9.5	8.8	8.5	7.8	7.6	7.4	7.2	6.8
	400	8.7	8.7	8.8	9.1	9.1	9.0	8.9	8.8	8.7	8.3	7.9	7.7	7.6	7.0	6.8	6.3	6.3	6.2	6.3	6.0
	500	6.7	6.6	6.8	6.9	6.8	6.7	6.8	6.8	6.6	6.3	6.1	6.0	6.1	5.7	5.6	5.6	5.5	5.5	5.5	5.5
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

DISTANCE

MEAN XBT TEMPERATURE, DEG-C

MID-NOVEMBER

	0	25.6	25.3	25.1	24.8	24.6	24.3	23.8	23.2	22.9	22.1	21.5	21.1	20.5	19.8	19.2	18.3	17.8	17.0	15.6	14.3
	10	25.5	25.3	25.1	24.8	24.6	24.3	23.8	23.2	22.9	22.1	21.4	21.1	20.5	19.8	19.1	18.3	17.8	17.0	15.6	14.3
	20	25.5	25.3	25.1	24.8	24.6	24.3	23.8	23.2	22.9	22.1	21.5	21.2	20.6	19.8	19.1	18.3	17.9	17.0	15.5	14.3
	30	25.5	25.3	25.1	24.7	24.6	24.3	23.8	23.2	22.8	22.1	21.5	21.1	20.6	19.9	19.2	18.3	17.9	17.0	15.4	13.8
	40	25.5	25.3	25.0	24.7	24.5	24.4	23.8	23.1	22.8	22.1	21.5	21.1	20.6	19.9	19.1	18.4	17.8	17.0	14.9	13.1
	50	25.4	25.3	24.9	24.6	24.5	24.2	23.7	23.1	22.6	22.0	21.1	20.9	20.3	19.4	18.7	17.7	17.2	16.5	14.3	11.8
D	60	25.3	25.2	24.6	24.3	24.0	23.7	23.2	22.8	22.1	21.5	20.5	20.2	19.5	18.5	17.7	16.4	16.1	15.3	13.1	10.8
E	70	25.1	25.0	24.0	23.8	23.1	22.7	22.6	22.1	21.2	20.5	19.7	19.3	18.4	17.7	16.6	15.2	15.0	14.0	12.1	10.2
P	80	24.4	24.4	23.3	23.1	22.1	21.8	21.7	21.1	20.3	19.5	19.0	18.6	17.5	17.0	15.8	14.5	14.1	13.0	11.3	9.9
T	90	23.5	23.6	22.7	22.2	21.3	21.1	20.7	20.4	19.6	18.7	18.5	18.0	16.9	16.4	15.4	13.9	13.3	12.3	10.7	9.7
H	100	22.7	22.8	22.1	21.6	20.7	20.4	20.0	19.8	19.0	18.1	17.9	17.5	16.5	15.9	15.0	13.4	12.8	11.8	10.3	9.4
	120	21.5	21.5	21.1	20.6	19.8	19.4	19.0	18.9	18.1	17.5	17.1	16.8	16.0	15.3	14.3	12.6	11.9	10.9	9.8	9.1
(M)	150	20.2	20.1	19.9	19.3	18.6	18.2	17.9	17.8	16.9	16.3	15.9	15.4	14.7	13.7	12.9	11.2	10.7	10.0	9.2	8.6
	200	17.5	17.3	17.5	17.0	16.2	15.9	15.5	15.5	14.2	13.8	12.9	12.6	12.1	11.2	10.7	9.7	9.3	8.9	8.4	7.9
	250	14.3	14.2	14.6	14.1	13.7	13.5	13.0	12.9	12.2	11.7	11.2	10.9	10.6	9.9	9.5	8.8	8.5	8.1	7.7	7.3
	300	11.7	11.7	12.0	11.9	11.6	11.6	11.3	11.3	10.9	10.5	10.0	9.8	9.6	8.9	8.5	7.9	7.7	7.4	7.2	6.8
	400	8.5	8.7	8.8	9.1	9.0	9.0	8.9	8.8	8.6	8.3	7.9	7.6	7.6	7.1	6.8	6.4	6.3	6.2	6.3	6.0
	500	6.6	6.6	6.7	6.8	6.8	6.8	6.7	6.7	6.6	6.3	6.1	6.1	6.1	5.8	5.7	5.6	5.5	5.5	5.5	5.5
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

DISTANCE

MEAN XBT TEMPERATURE, DEG-C 01 DECEMBER

	0	25.1	24.8	24.5	24.2	23.9	23.7	23.2	22.6	22.2	21.3	20.7	20.4	19.8	19.1	18.3	17.7	17.1	16.3	14.9	13.6
	10	25.1	24.8	24.5	24.2	23.9	23.7	23.1	22.6	22.2	21.3	20.7	20.4	19.8	19.1	18.3	17.7	17.1	16.3	14.9	13.6
	20	25.1	24.8	24.5	24.2	23.9	23.7	23.2	22.6	22.2	21.3	20.8	20.4	19.8	19.1	18.3	17.6	17.1	16.3	14.9	13.6
	30	25.1	24.8	24.5	24.2	23.9	23.7	23.2	22.6	22.2	21.3	20.8	20.4	19.8	19.1	18.3	17.6	17.3	16.4	14.8	13.4
	40	25.0	24.8	24.5	24.2	23.9	23.7	23.2	22.6	22.2	21.3	20.9	20.4	19.9	19.2	18.4	17.7	17.3	16.4	14.6	12.9
	50	25.0	24.8	24.5	24.2	24.0	23.7	23.2	22.7	22.2	21.3	20.6	20.3	19.8	19.1	18.3	17.4	17.0	16.2	14.2	11.9
D	60	25.0	24.9	24.3	24.0	23.7	23.4	23.0	22.5	22.0	21.1	20.4	20.0	19.4	18.6	17.7	16.4	16.2	15.2	13.2	10.9
E	70	25.0	24.8	23.9	23.7	23.0	22.7	22.7	22.0	21.4	20.4	19.8	19.3	18.6	18.0	16.8	15.3	15.3	14.1	12.2	10.3
P	80	24.4	24.3	23.5	23.1	22.2	22.0	21.9	21.3	20.7	19.6	19.4	18.7	17.7	17.3	16.0	14.7	14.3	13.1	11.3	9.9
T	90	23.5	23.6	22.9	22.4	21.4	21.3	20.9	20.6	19.9	18.8	18.9	18.1	17.1	16.6	15.5	14.0	13.3	12.3	10.8	9.7
H	100	22.8	22.8	22.4	21.7	20.8	20.6	20.1	19.9	19.3	18.3	18.2	17.5	16.7	16.0	15.0	13.5	12.8	11.7	10.4	9.4
	120	21.5	21.4	21.3	20.6	19.9	19.5	19.0	18.9	18.2	17.4	17.3	16.8	16.1	15.3	14.3	12.7	12.0	10.8	9.7	9.0
(M)	150	20.1	19.9	20.0	19.3	18.6	18.2	17.9	17.7	16.9	16.2	16.0	15.4	14.7	13.8	12.8	11.3	10.7	9.9	9.1	8.6
	200	17.3	17.3	17.7	16.7	16.1	15.9	15.4	15.4	14.2	13.7	12.9	12.6	12.1	11.3	10.6	9.7	9.3	8.9	8.4	8.0
	250	14.0	14.2	14.7	13.9	13.5	13.4	12.9	12.8	12.2	11.7	11.1	10.9	10.6	10.0	9.5	8.9	8.5	8.1	7.7	7.4
	300	11.5	11.6	12.0	11.8	11.6	11.6	11.2	11.2	10.8	10.5	10.0	9.8	9.6	8.9	8.4	8.0	7.7	7.3	7.2	6.8
	400	8.4	8.7	8.8	9.0	9.0	9.0	8.8	8.7	8.6	8.4	7.8	7.6	7.6	7.2	6.7	6.5	6.4	6.2	6.3	6.0
	500	6.6	6.6	6.6	6.7	6.8	6.8	6.7	6.7	6.7	6.3	6.1	6.1	6.0	5.9	5.7	5.6	5.5	5.6	5.6	5.4
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
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DISTANCE

MEAN XBT TEMPERATURE, DEG-C MID-DECEMBER

	0	24.5	24.3	23.8	23.6	23.2	22.9	22.4	22.0	21.5	20.5	20.0	19.6	18.9	18.3	17.4	17.0	16.3	15.5	14.3	12.9
	10	24.5	24.3	23.8	23.6	23.2	22.9	22.4	22.0	21.5	20.4	20.0	19.5	18.9	18.3	17.4	17.0	16.3	15.6	14.3	12.9
	20	24.5	24.3	23.8	23.6	23.2	22.9	22.4	22.0	21.5	20.4	20.0	19.5	18.9	18.3	17.4	16.9	16.3	15.6	14.3	12.8
	30	24.5	24.2	23.8	23.6	23.2	22.9	22.4	22.0	21.5	20.4	20.0	19.6	18.9	18.4	17.5	16.9	16.4	15.7	14.3	12.8
	40	24.5	24.3	23.9	23.7	23.2	23.0	22.4	22.0	21.5	20.5	20.1	19.6	19.0	18.5	17.6	16.8	16.5	15.7	14.2	12.5
	50	24.5	24.3	23.9	23.6	23.3	23.0	22.5	22.1	21.5	20.5	20.0	19.7	19.1	18.5	17.7	16.9	16.5	15.7	14.1	11.9
D	60	24.6	24.3	23.8	23.6	23.1	22.9	22.6	22.1	21.6	20.5	20.0	19.6	19.1	18.4	17.5	16.4	16.1	15.1	13.4	11.2
E	70	24.6	24.3	23.7	23.5	22.8	22.5	22.5	21.8	21.4	20.2	19.8	19.2	18.6	18.1	16.9	15.5	15.5	14.3	12.5	10.5
P	80	24.2	23.9	23.4	23.1	22.2	22.0	21.9	21.3	20.9	19.6	19.5	18.8	17.9	17.5	16.2	15.0	14.4	13.3	11.6	9.9
T	90	23.5	23.3	23.0	22.5	21.5	21.4	21.0	20.8	20.2	19.1	19.2	18.3	17.4	16.9	15.7	14.2	13.3	12.4	11.0	9.7
H	100	22.9	22.6	22.5	21.9	21.0	20.8	20.2	20.0	19.6	18.5	18.6	17.7	16.9	16.2	15.0	13.7	12.7	11.8	10.6	9.5
	120	21.5	21.2	21.2	20.6	20.0	19.6	19.0	18.9	18.4	17.4	17.6	16.9	16.1	15.3	14.3	12.9	11.9	10.9	9.9	9.1
(M)	150	20.1	19.7	19.9	19.2	18.6	18.2	17.8	17.5	17.0	16.1	16.1	15.6	14.7	13.9	12.8	11.5	10.6	9.9	9.2	8.7
	200	17.2	17.2	17.6	16.6	16.1	15.8	15.3	15.2	14.4	13.5	13.1	12.7	12.0	11.4	10.5	9.8	9.3	8.9	8.5	8.0
	250	13.9	14.1	14.7	13.7	13.4	13.3	12.8	12.6	12.2	11.7	11.1	10.9	10.5	10.0	9.5	8.9	8.5	8.1	7.8	7.4
	300	11.4	11.5	12.0	11.7	11.5	11.5	11.2	11.2	10.9	10.5	9.9	9.8	9.5	9.0	8.4	8.0	7.7	7.3	7.2	6.9
	400	8.3	8.6	8.8	8.9	8.9	8.9	8.8	8.7	8.6	8.3	7.8	7.7	7.5	7.2	6.7	6.5	6.4	6.2	6.2	6.1
	500	6.6	6.6	6.6	6.7	6.9	6.8	6.7	6.6	6.6	6.4	6.2	6.2	5.9	5.8	5.7	5.6	5.5	5.6	5.6	5.5
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

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NOAA Technical Report NMFS SSRF-729

References for the Identification of Marine Invertebrates on the Southern Atlantic Coast of the United States

Richard E. Dowds

April 1979

U.S. DEPARTMENT OF COMMERCE
Juanita M. Kreps, Secretary
National Oceanic and Atmospheric Administration
Richard A. Frank, Administrator
Terry L. Leitzell, Assistant Administrator for Fisheries

National Marine Fisheries Service

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References for the Identification of Marine Invertebrates on the Southern Atlantic Coast of the United States

RICHARD E. DOWDS[1]

ABSTRACT

This collection of 638 citations provides an entry to the taxonomic literature on invertebrates of the continental shelf and estuaries from the Chesapeake Bay to northeastern Florida. Many of the citations are annotated and most include a list of North Carolina libraries in which they can be found. Author and systematic indices are provided.

INTRODUCTION

s bibliography has been compiled to provide an
to the taxonomic literature on invertebrates of the
inental shelf and estuaries from Chesapeake Bay to
eastern Florida. I have emphasized summary works
ng large groups; the bibliographies of such works
ead one to the more specialized and detailed
ature of those groups. Ecological material has been
led when it seemed particularly valuable. I
ize that, even within these limitations, this com-
ion is incomplete; useful works may have been over-
ed and new ones are continually being published.

any cases the citation is followed by a list of North
na libraries in which it can be found. For books,
listings are complete only for the libraries of the
rsity of North Carolina, Zoology Department,
l Hill, and the Institute of Marine Sciences,
ead City. For journals, however, I have been able
cord the holdings of the libraries listed below thanks
invaluable publications: Littleton, I. T., and G.
ouser (editors). 1967. *North Carolina Union List*
entific Serials, North Carolina State University,
igh; and Moreland, M. C. (editor). 1973. *Marine*
ure: Serial publications in libraries of the coastal
region, Part II: North Carolina, Coastal Plains
er for Marine Development Services, Wilmington.

ries

UNC-ZOOL	Zoology Department, University of North Carolina at Chapel Hill
UNC-MAIN	L. R. Wilson Library, University of North Carolina at Chapel Hill
IMS	Institute of Marine Sciences, University of North Carolina, Morehead City
DUKE-BIOL	Biology-Forestry Library, Duke University, Durham
DUML	Duke University Marine Laboratory, Beaufort
NCSU	D. H. Hill Library, North Carolina State University, Raleigh
NMFS	National Marine Fisheries Service Laboratory, Beaufort
ALL	refers to all of the above libraries.

Occasionally I have included other libraries in the listings, namely:

UNC-BOT	Botany Department, University of North Carolina at Chapel Hill
UNC-GEOL	Geology Department, University of North Carolina at Chapel Hill
UNC-HEALTH	Health Affairs Library, University of North Carolina at Chapel Hill
DUKE-GEN	W. R. Perkins Library, Duke University, Durham
DUKE-MED	Medical Center Library, Duke University, Durham
UNC-WILM	University of North Carolina at Wilmington.

The work of compiling this list of references has been aided by the efforts of many people. Numerous references have been obtained from earlier lists compiled by the Duke University Marine Laboratory and Deborah M. Dexter and from several of the books listed under Invertebrates - General. References, advice, and clerical help have been contributed by Lawrence Burns, A. F. Chestnut, Michael Crezée, Patricia Finn, Richard S.

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iversity of North Carolina, Institute of Marine Sciences, Morehead
C 28557, and Department of Zoology, Chapel Hill, NC 27514;
address: 24 Briarwood Trail, Weymouth, MA 02188.

Fox, Thomas H. Fox, Stephen L. Gardiner, Jeffrey D. Green, J. Thompson Hunter, Charles E. Jenner, Eric Lindgren, David Nixon, Hugh J. Porter, Frank J. Schwartz, Sarah G. Tomlinson, S. Ann Watkins, Austin B. Williams, and W Herbert Wilson.

INVERTEBRATES - GENERAL

CARRIKER, M. R., coordinator.
Marine flora and fauna of the northeastern United States. (IMS, NMFS, NCSU, DUKE-BIOL. A series of pictoral keys being published in the National Marine Fisheries Service Circulars. Only a few issues have been completed but many more are anticipated. They cover the region from Maine to Virginia but many should have utility further south.)

GOSNER, K. L.
1971. Guide to identification of marine and estuarine invertebrates, Cape Hatteras to the Bay of Fundy. John Wiley & Sons, Inc., N.Y., 693 p. (IMS, UNC-ZOOL, DUML. Although its illustrations could be better and many southern species are not included, it should be useful for non-specialists. The extensive keys are particularly valuable for determining higher level taxa.)

HULINGS, N. C. (editor).
1971. Proceedings of the First International Conference on Meiofauna. Smithson. Contrib. Zool. 76, 205 p. (UNC-ZOOL, NMFS. Contains much systematic and ecological information concerning animals which live among sand grains. Some individual papers are listed elsewhere in this bibliography.)

HULINGS, N. C., and J. S. GRAY.
1971. A manual for the study of meiofauna. Smithson. Contrib. Zool. 78, 84 p. (IMS, UNC-ZOOL, NMFS. Techniques for collection and preservation with some references to systematic papers.)

KIRBY-SMITH, W. W., and I. E. GRAY.
1971. A checklist of common marine animals of Beaufort, North Carolina. Duke Univ. Mar. Lab., Mimeogr., 33 p. (DUML. Common invertebrates listed by habitat.)

McERLEAN, A. J., C. KERBY, and M. L. WASS (editors).
1972. Biota of the Chesapeake Bay. Chesapeake Sci. 13 Suppl.:S1-S197. (ALL except IMS and UNC-MAIN. Summaries of the taxonomic and ecological knowledge of groups found in Chesapeake Bay with discussion of biological criteria for assessing environmental change. Neither species descriptions nor keys are included, but these can be found in some of the references cited. Some individual papers are listed elsewhere in this bibliography.)

MINER, R. W.
1950. Field book of seashore life. G. P. Putnam's Sons, N.Y., 888 p. (IMS, UNC-ZOOL, DUML. Coverage extends only to Cape Hatteras an cludes only common species. Some systema nomenclature is out of date. No keys are provid In spite of these shortcomings, the wide scop good drawings make it useful for inexperie students.)

PRATT, H. S.
1935. A manual of the common inverte animals (exclusive of insects). McGraw- Book Co., Inc., N.Y., 854 p. (UNC-ZOOL. Sh descriptions of taxa from phylum to species keys to taxa from class to family or g Emphasis is on species from eastern Uni States. Some nomenclature is out of date.)

SMITH, R. I. (editor).
1964. Keys to marine invertebrates of the W Hole Region. Syst.-Ecol. Prog., Mar. Biol. La Woods Hole, Mass., 208 p. (UNC-ZOOL, Does not include many southern species, b useful for higher level taxa. Quality of cha variable.)

WASS, M. L. (editor).
1972. A check-list of the biota of lower Chesa Bay with inclusions from the upper bay and Virginia Sea. Va. Inst. Mar. Sci., Spec. Sci. R 65, 290 p. (IMS. Includes a bibliography.)

The following works are useful for placing an unkno planktonic animal in the proper higher level gr (phylum, class, order). References in the phylum lis are usually necessary for identification to lower le

DAVIS, C. C.
1955. The marine and fresh-w plankton. Michigan State Univ. Press, Lansing, 562 p. (UNC-ZOOL, DUKE-BIO DUML. Contains keys to phyla and some taxa, and illustrations of representatives of groups.)

JOHNSTONE, J., A. SCOTT, and H. C. CHADWIC
1924. The marine plankton. University Liverpool, 194 p. (DUKE-BIOL. Of some although most species are British.)

NEWELL, G. E., and R. C. NEWELL.
1963. Marine plankton: a pract guide. Hutchinson Educational Ltd., Lond p. (UNC-ZOOL. Short descriptions and illust tions, but no keys, of British species. Usef determining higher level taxa.)

VANNUCCI, M.
1959. Catalogue of marine larvae. No. 1. Forewa the concept of larva, the fundamental types vae. Inst. Oceanogr., Univ. São Paulo, Paulo, Brazil, 44 p. (The first number in a se that is intended eventually to provide descripti and illustrations of all species of marine l This general introduction has descriptions a lustrations of the major kinds of larvae.)

WICKSTEAD, J. H.
1965. An introduction to the study of tr

plankton. Hutchinson & Co., Ltd., Lond., 160 p. (UNC-ZOOL. Contains short descriptions and illustrations of representatives of many groups, but no keys.)

ECOLOGICAL INFORMATION

eral

IKER, M. R.

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PHYLUM ARTHROPODA

Most members of the Classes Chilopoda, Diplo
Insecta, and Arachnida are terrestrial or fresh
animals. Only a few (for example, the members of t
sect genus *Halobates* and most of the mite f
Halacaridae) are wholly marine; however, many
spend a portion of their life in marine or brackish w
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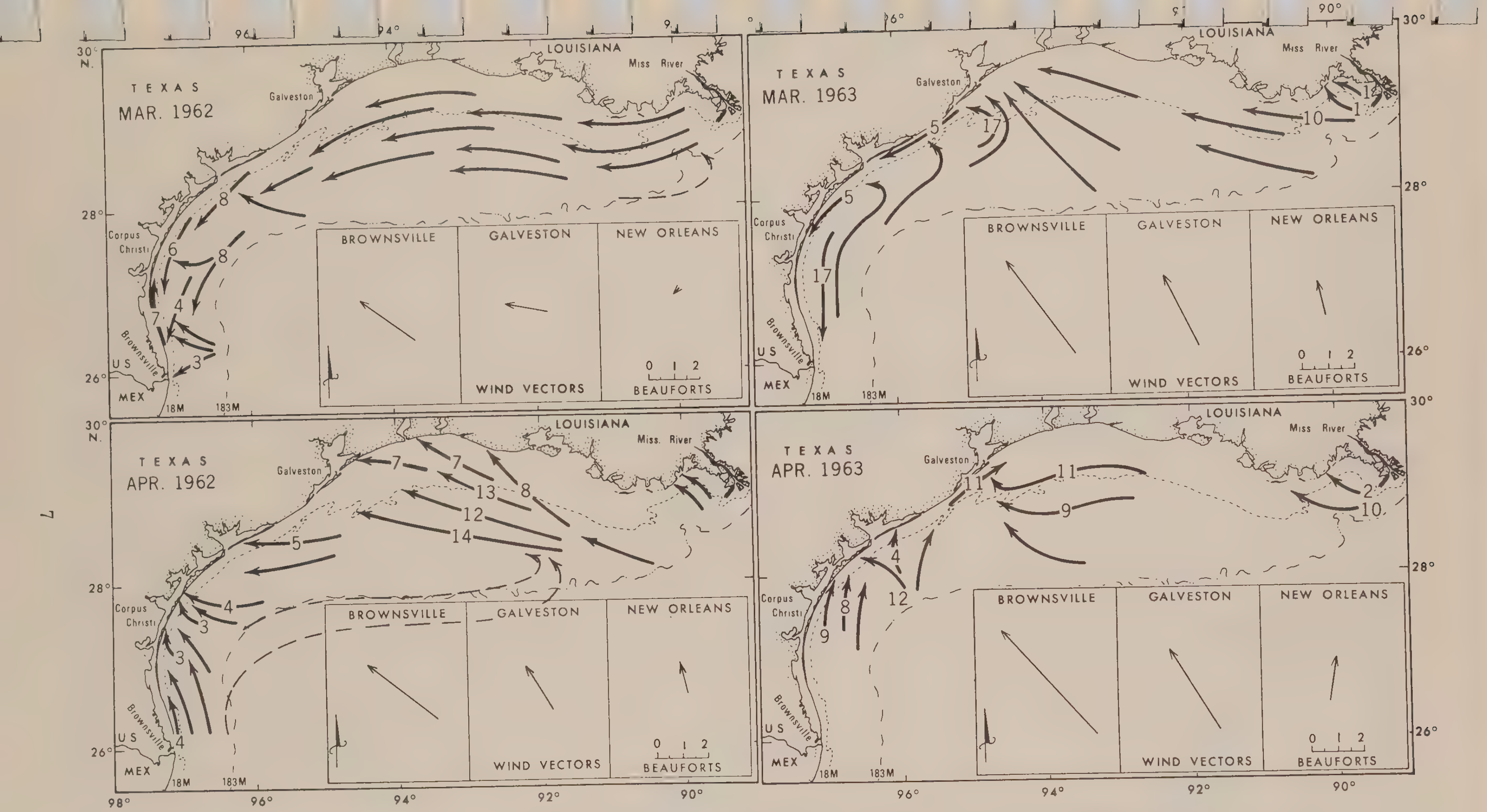
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92°
90°
30°

Figure 3.—Surface circulation deduced from recoveries of drift bottles released in March and April 1962 and 1963 in the northwestern Gulf of Mexico. (Arrows indicate direction of flow; numbers indicate average km/day).

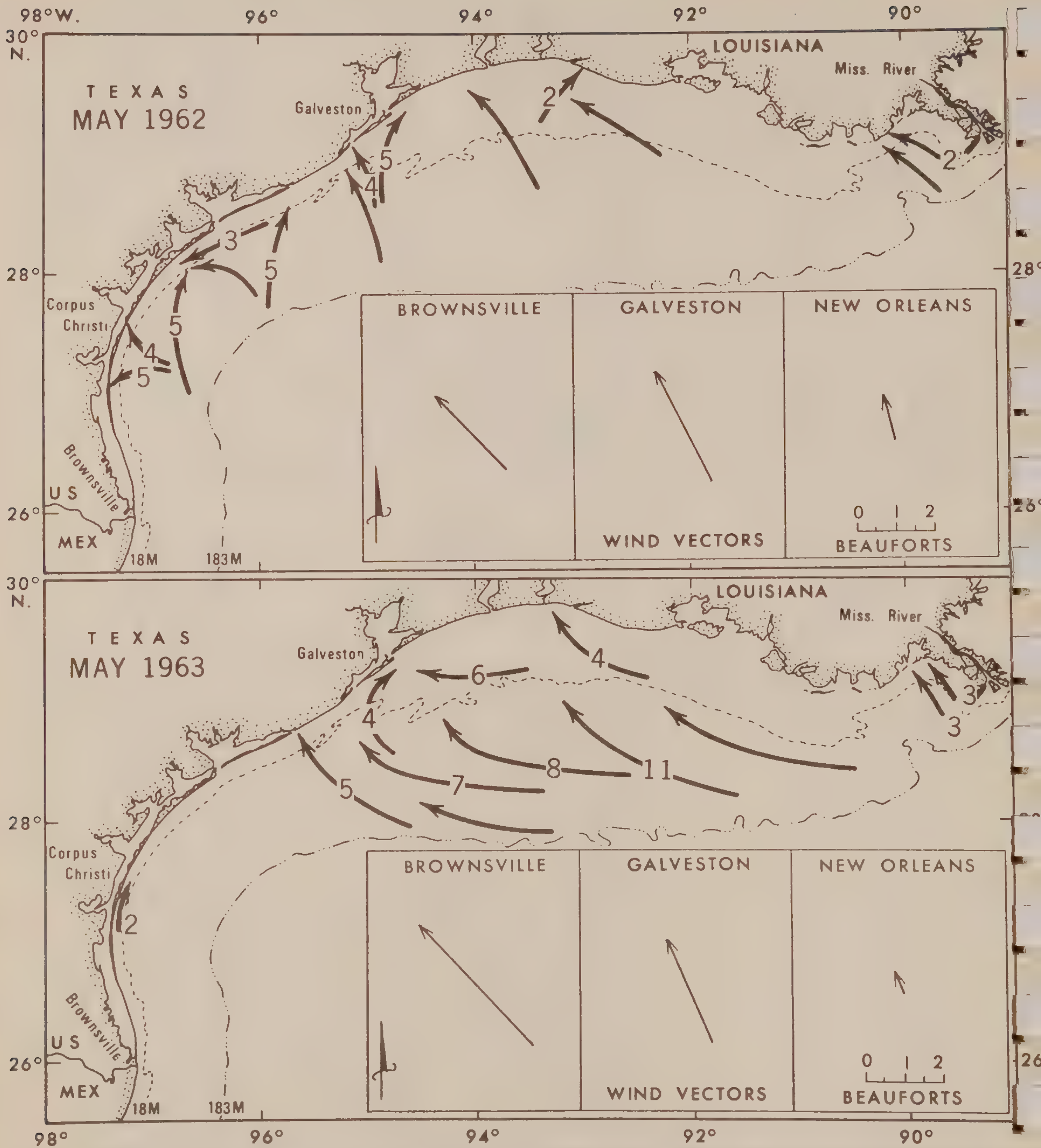
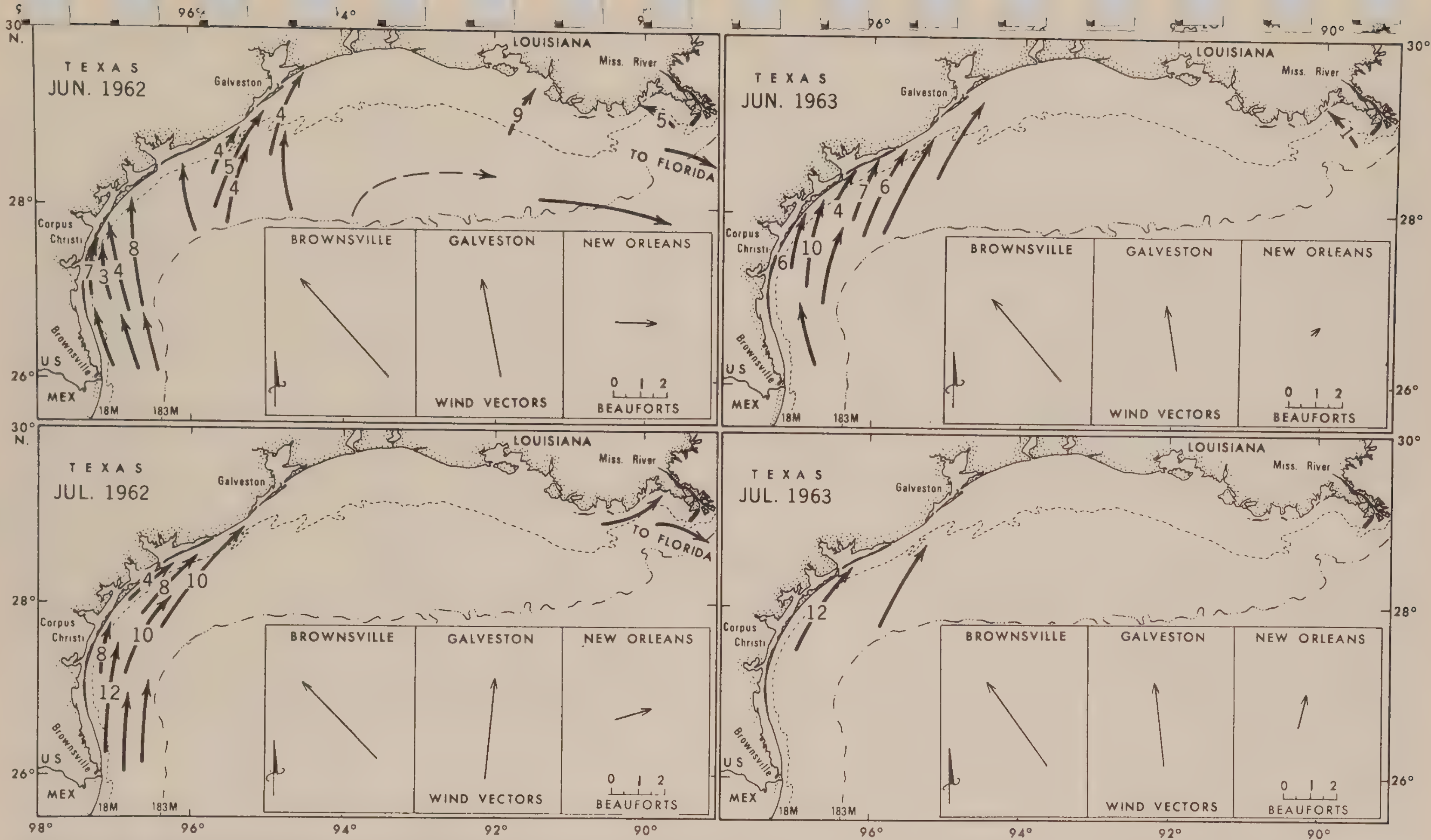

98°W.
96°
94°
92°
90°
30° N.
TEXAS
MAY 1962
Galveston
LOUISIANA
Miss. River
2
2
2
5
4
3
5
5
4
5
28°
Corpus Christi
Brownsville
US
MEX
26°
18M
183M
BROWNSVILLE
GALVESTON
NEW ORLEANS
WIND VECTORS
0 1 2
BEAUFORTS
30° N.
TEXAS
MAY 1963
Galveston
LOUISIANA
Miss. River
4
6
4
3
3
8
11
7
5
2
28°
Corpus Christi
Brownsville
US
MEX
26°
18M
183M
BROWNSVILLE
GALVESTON
NEW ORLEANS
WIND VECTORS
0 1 2
BEAUFORTS
98°
96°
94°
92°
90°

Figure 4.—Surface circulation deduced from recoveries of drift bottles released in May 1962 and 1963 in the northwestern Gulf of Mexic (Arrows indicate direction of flow; numbers indicate average km/day).

day with an overall average of about 6. In general velocities of surface currents decreased from March to May as currents became more onshore.

With few exceptions, winds were generally similar between years over the study area, but a marked seasonal shift in direction was apparent. Resultant wind vectors indicated that the winds became more southerly or onshore during this 3-mo period and may account for the general weakening of the east to west flow of surface waters off Louisiana and east Texas as well as a shift surface currents to the north off south Texas. With t exception of May 1962, wind force was greate Brownsville.

June-July.—Following the March-April transition period, the dominant east to west flow of Jan February had in essence reversed (Fig. 5). Cur flowed northward along the south Texas coast, where


TEXAS
JUN. 1962
LOUISIANA
Galveston
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Brownsville
US
MEX
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9
5
18M
183M
BROWNSVILLE
GALVESTON
NEW ORLEANS
WIND VECTORS
0 1 2
BEAUFORTS
TEXAS
JUN. 1963
6
10
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TEXAS
JUL. 1962
8
12
10
4
8
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TEXAS
JUL. 1963
12
30°
N.
28°
26°
98°
96°
94°
92°
90°

Figure 5.—Surface circulation deduced from recoveries of drift bottles released in June and July 1962 and 1963 in the northwestern Gulf of Mexico. (Arrows indicate direction of flow; numbers indicate average km/day).

off Louisiana currents were to the north or east with the northerly current generally restricted to nearshore waters and the eastward movement restricted to the deeper waters over the shelf. The strength of this eastward flow was apparently greater in 1962 than in 1963 as evidenced by the recovery of bottles as far away as Florida within 30 days after release. In 1963, bottles were also recovered in Florida but time adrift exceeded 30 days and the recoveries therefore are not shown in Figure 5.

Current velocities varied throughout the study area with values ranging from 3 to 12 km/day along the Texas coast and averaging 7 km/day. Onshore currents along the Louisiana coast ranged from 1 to 9 km/day with an average of 3 km/day. Monthly velocities were similar between years.

The influence of the prevailing southerly wind so characteristic of the summer in the northwestern Gulf of Mexico was readily apparent at Brownsville and Galveston for June and July of both years. Surface water currents off Texas were observed flowing either directly downwind or slightly to the right of the prevailing wind direction. Off Louisiana, however, the wind direction varied between years. In 1962, air flow was to the east whereas in 1963 it was more to the north. This variation generally supports the stronger eastward movement of surface waters off Louisiana in 1962.

August.—Drift bottles were released during this time period only in 1963, and their movements indicated still another transitional period in current direction and velocity (Fig. 6). Surface currents, rather than moving alongshore and to the north, had shifted to onshore toward the west; velocities had slowed to a rate of km/day, a marked decrease from those veloci observed in the June-July period.

At Brownsville and Galveston winds were generally southeasterly. At New Orleans, winds were variable, evidenced by the relatively small resultant vector, were northwesterly.

September-December.—The release and recovery drift bottles indicated that surface currents had returned to the dominant flow noted in January-February, i.e., a general west to southwesterly flow (Figs. 7, 8). Seve features of the circulation pattern, however, should noted. First, recoveries of bottles in the vicinity of Brownsville, Texas, in 1962 indicated a westerly onshore movement that dissipated as the season progressed.

Second, the onshore component of the prevai southwest current was not as apparent in 1963 as in 1962. Few bottles released in the study area were recovered within 30 days, and of those that were, most w released at nearshore stations. Whether this was du the lack of areal coverage or the total number of bottles released is not known, but the results were similar those observed in December 1962 (Fig. 8), a period w a large number of bottles were released and areal coverage was extensive. This absence of recoveries may indicate either an along- or offshore movement of surf waters.

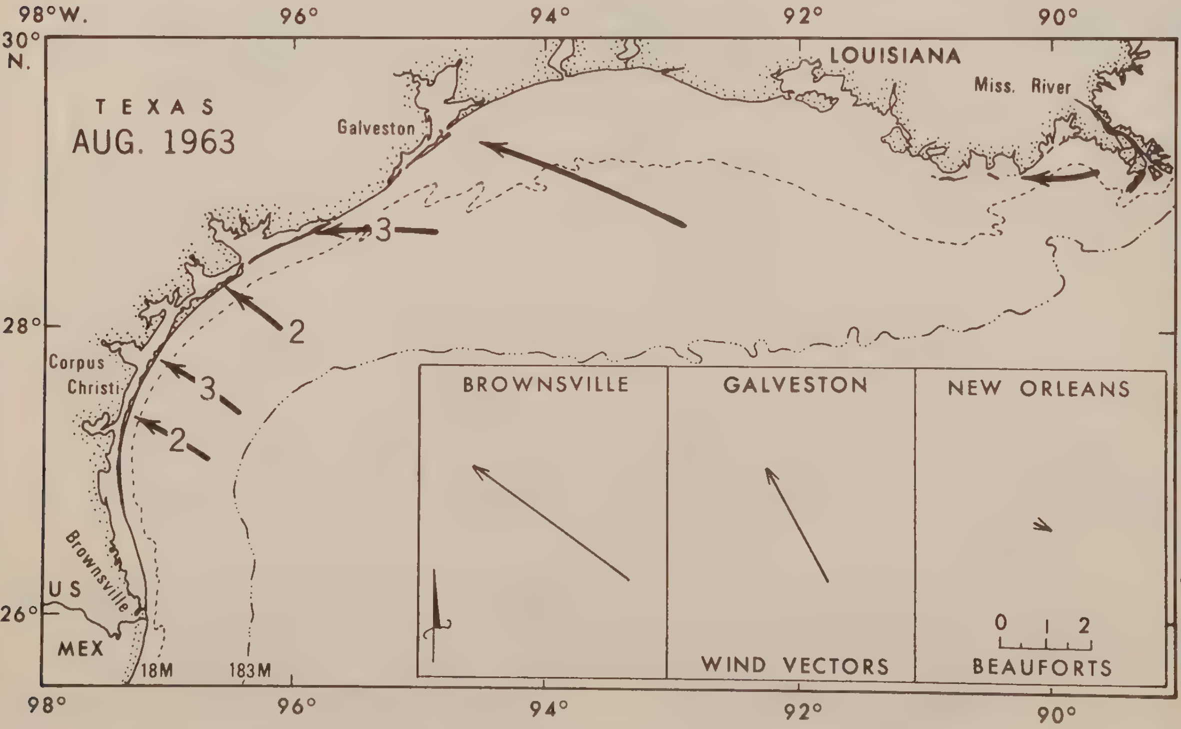
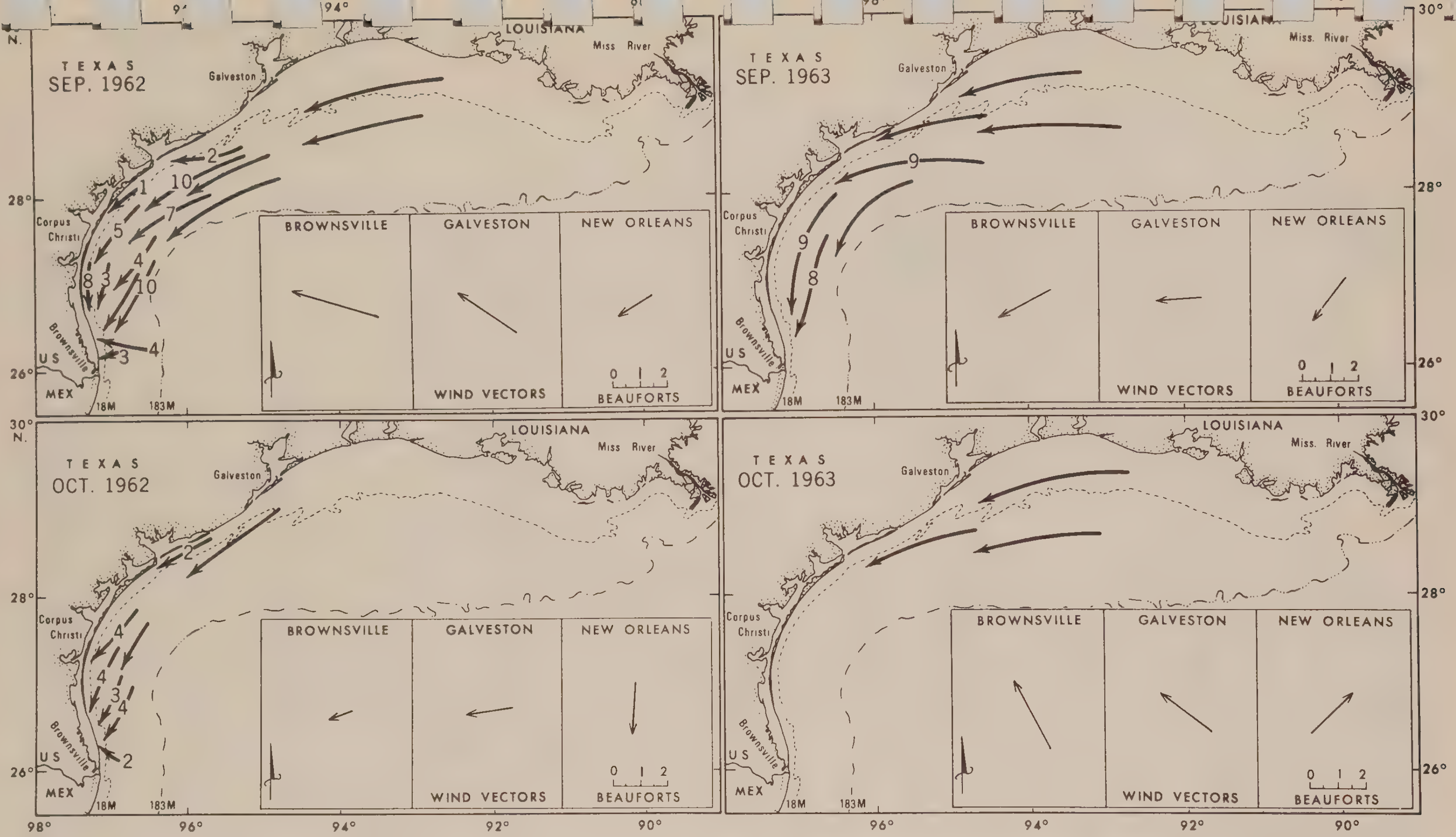


Figure 6.—Surface circulation deduced from recoveries of drift bottles released in August 1963 in the northwestern Gulf of Mexico. (Ar indicate direction of flow; numbers indicate average km/day).


TEXAS
SEP. 1962
TEXAS
SEP. 1963
TEXAS
OCT. 1962
TEXAS
OCT. 1963
LOUISIANA
Miss River
Galveston
Corpus Christi
Brownsville
US
MEX
18M
183M
BROWNSVILLE
GALVESTON
NEW ORLEANS
WIND VECTORS
0 1 2
BEAUFORTS
2
10
1
7
5
4
8
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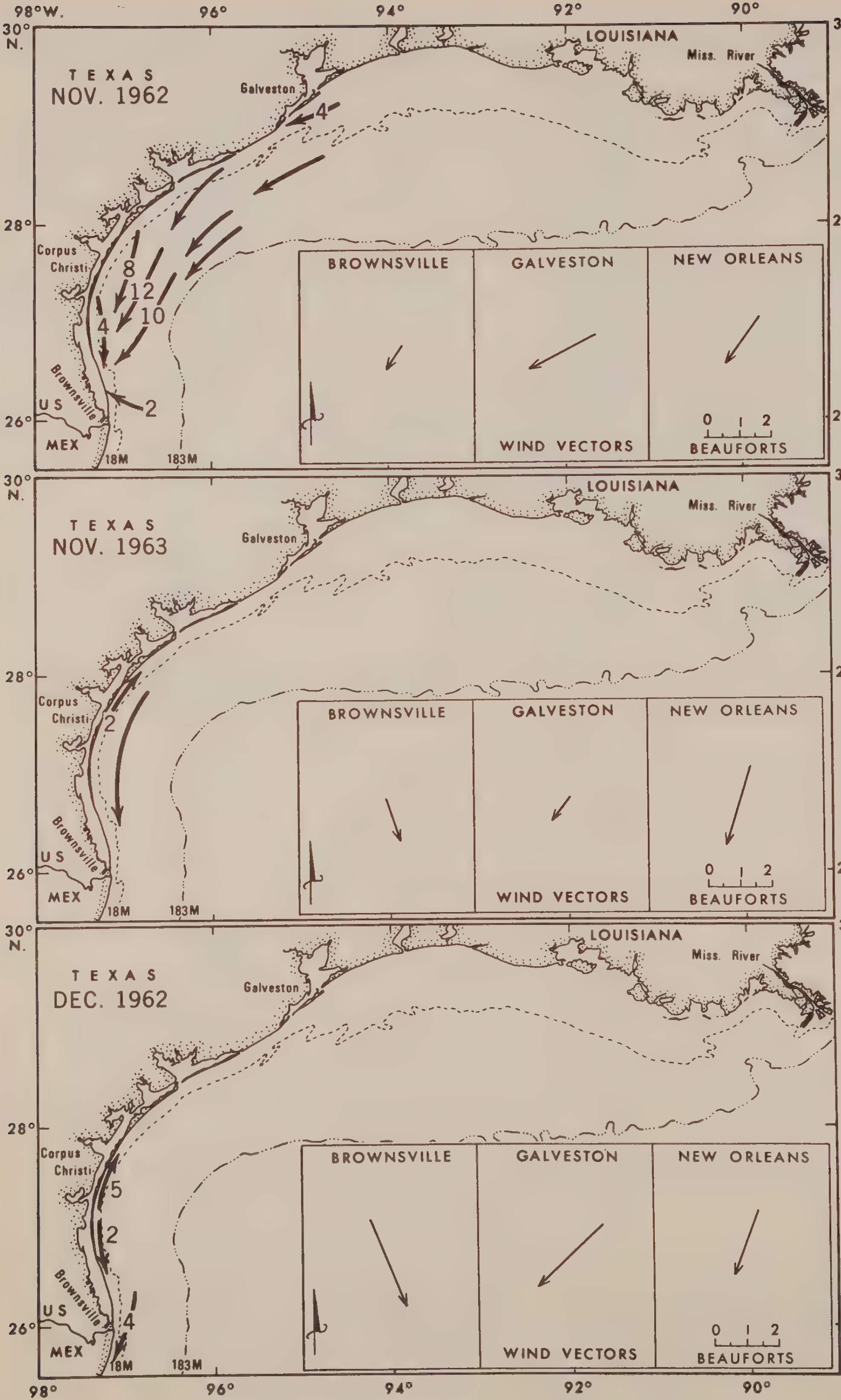
2
30°
N.
28°
26°
98°
96°
94°
92°
90°

Figure 7.—Surface circulation deduced from recoveries of drift bottles released in September and October 1962 and 1963 in the northwestern Gulf of Mexico. (Arrows indicate direction of flow; numbers indicate a average km/day).


98°W.
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30° N.
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28°
26°
TEXAS
NOV. 1962
NOV. 1963
DEC. 1962
LOUISIANA
Miss. River
Galveston
Corpus Christi
Brownsville
US
MEX
18M
183M
4
8
12
10
4
2
2
5
2
4
BROWNSVILLE
GALVESTON
NEW ORLEANS
WIND VECTORS
0 1 2
BEAUFORTS
98°
96°
94°
92°
90°

Figure 8.—Surfa circulation deduced from recoveries of drift bottles released i November 196 and 1963, and December 1962 in the northwester Gulf of Mexico Arrows indicat direction of flow; numbers indicate average km/day)

ble 4.—Estimated range and average current velocity for September-December 1962-63 in the northwestern Gulf of Mexico.

	1962		1963	
	Range	Average	Range	Average
ber	1-10	5	8-9	9
r	2-4	3	no data	
vember	2-12	7	no data	
cember	2-5	3	no data	

Information on current velocities was generally icted to the 1962 data, but no distinct trend was lly apparent. Ranges and averages for each month re shown in Table 4.

The seasonal shift in wind circulation over the study during this period agreed generally with the direc- of surface water movement. With few exceptions, ast to southeast winds became more northerly until in ovember 1963 and December 1962 north winds nated over the entire study area. The lack of drift e recoveries during this period supports the implied ffshore southerly flow of surface waters.

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Surface Circulation in the Northwestern Gulf of Mexico as Deduced From Drift Bottles

Robert F. Temple and John A. Martin

May 1979

U.S. DEPARTMENT OF COMMERCE
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rface Circulation in the Northwestern Gulf of Mexico as Deduced From Drift Bottles[1]

ROBERT F. TEMPLE and JOHN A. MARTIN[2]

ABSTRACT

Drift bottles were released monthly at predetermined stations in the northwestern Gulf of Mexico from February 1962 to December 1963. Of the total 7,863 bottles released, 12% (953) were recovered within 30 days after release. Analysis of the monthly recoveries revealed seasonal shifts in the flow of surface waters. Between September and February the dominant flow was west along the Louisiana and east Texas coasts, shifting southwest along the southern Texas coast. Between March and May, currents underwent a transitional period, shifting to the north and onshore, particularly along the south and central Texas coast. Converging currents, also apparent along the south Texas coast, appeared to progress up the coast with time. In June and July the surface flow was to the northeast and east. August was another transitional period with currents appearing to weaken and turning onshore. Movements of surface waters appeared directly related to prevailing winds.

INTRODUCTION

As part of an expanded research effort in 1962 (Kut-
963), the Bureau of Commercial Fisheries, now
ional Marine Fisheries Service, NOAA, initiated
rift bottle study to determine the direction and rate of
surface waters in the northwestern Gulf of Mex-
e objectives of this study were: 1) to document on
onthly basis surface current direction and velocity;
2) to attempt to relate monthly variations in current
n and speed with the success or failures of the
hrimp crops. Shrimp are planktonic, and may be
pendent upon currents for transportation to the estu-
ne nursery grounds, which are essential for successful
ion of their life cycle. The drift bottle study
d herein began in 1962 and continued through
3.

Seasonal difference in direction and speed of surface
s in the Gulf of Mexico have been generally de-
by Smith et al. (1951), Leipper (1954), Curray
60), Chew et al. (1962), and Ichiye (1962). More recent
n current include those by Drennan (1963), Dren-
al. (1963), Armstrong et al. (1967), Watson and
hrens (1970), Ichiye and Sudo (1971),[3] and Moore
73). Many of the above studies, however, although
ting to an understanding of ocean currents in the
ere restricted to limited geographic areas and
pleted over relatively short time periods. The data
sented in this report are unique in that they were
ed from the entire northwestern Gulf of Mexico and on a monthly basis for a 2-yr period, thus providing a time series heretofore unavailable.

METHODS

Cruises were conducted monthly with chartered shrimp vessels from February 1962 to November 1963 to stations located over the continental shelf (Fig. 1). The monthly schedule was followed as closely as possible, the only exceptions being due to adverse weather conditions or mechanical breakdowns. Operations were similar between years except that fewer stations were occupied in 1963, and one vessel was used to cover the entire study area rather than two as in 1962. The general overall effects of these modifications were that in 1963 the areal coverage was slightly reduced, and the time required to provide total coverage of the study area was increased. The latter effect explains seeming discrepancies in the date labeling of figures used in the analysis to follow. For example, the April cruise in 1963 extended into May.

Drift bottles used throughout the study were made of clear glass, about 22 cm in height, 6 cm in diameter, and had a capacity of about 240 cm^3. Each bottle contained a bright reddish-orange card on which was a brief message in Spanish and English. A reward of 50 cents was paid for the return of the card with information of location and date of recovery. In most cases, half the bottles released at a station were ballasted (odd numbers) and half were unballasted (even numbers). Those ballasted floated at or just under the surface. The reason for the use of the two types of bottles was an attempt to determine the direct effects of winds.

The number of bottles released during each cruise varied during the 2-yr study. Generally, 12 bottles were released at each station in 1962; 4-10 bottles were released per station in 1963. This modification did not affect the rate of recovery for bottles within 30 days after release for the percent recovered in 1963 was greater than

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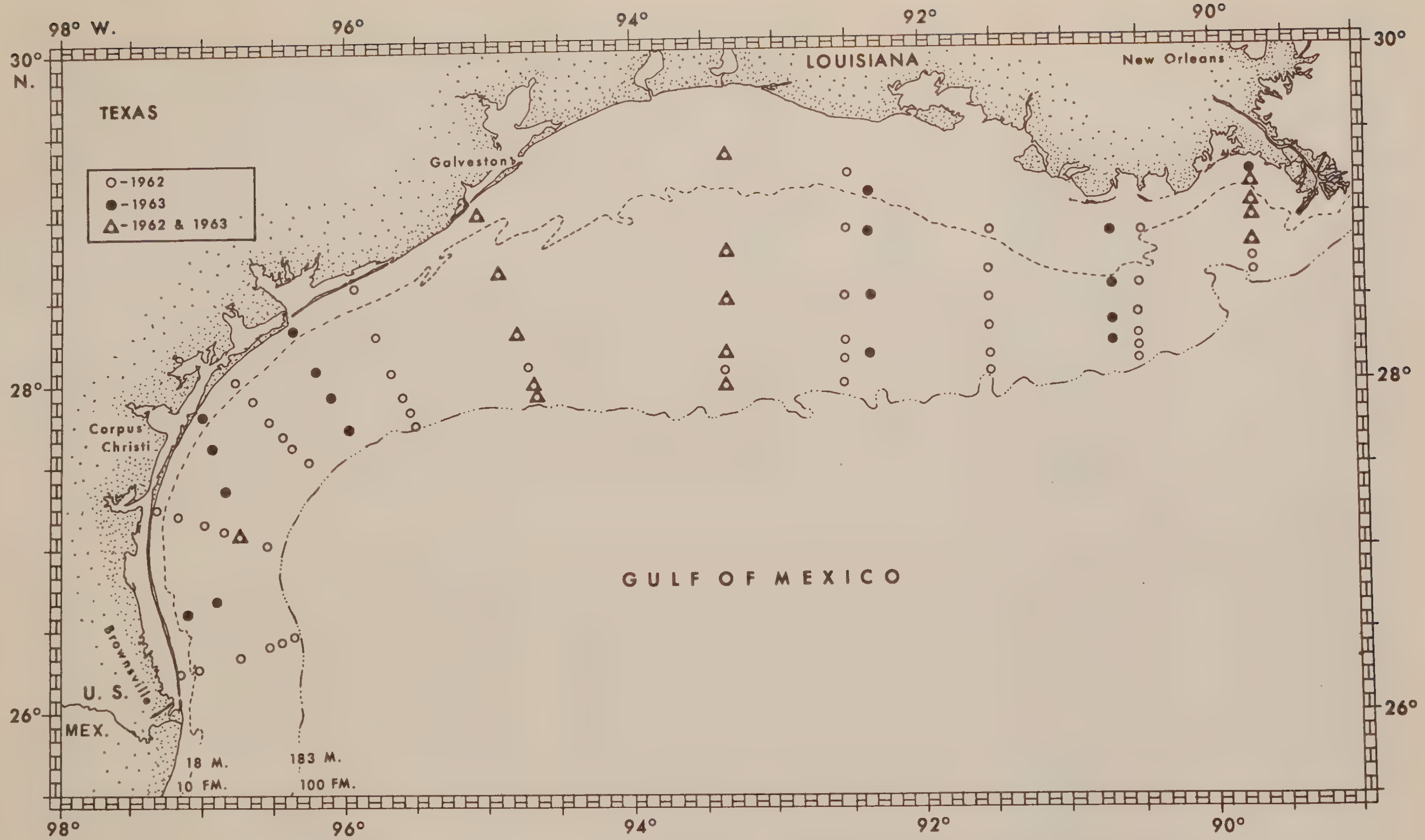
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26°
TEXAS
LOUISIANA
New Orleans
Galveston
Corpus Christi
Brownsville
U. S.
MEX.
GULF OF MEXICO
○-1962
●-1963
△-1962 & 1963
18 M.
10 FM.
183 M.
100 FM.
98°
96°
94°
92°
90°

Figure 1.—The drift bottle study area in the northwestern Gulf of Mexico with the location of stations occupied in 1962 and 1963.

n 1962 (Table 1). This increase was probably due to reater public awareness of the program in 1963 than in

The technique used to depict surface currents was the ame as used by Day (1958). Recovered bottles were d into two time periods of 15 days each, i.e., 0-15 nd 16-30 days. The 0-15 day recoveries were first lotted as straight lines connecting points of release and ecovery. These lines were resolved into directional ar- nd over these arrows we then plotted, as straight he 16-30 day recoveries. The final step was to educe the 16-30 day straight lines to flow arrows conrming with the 0-15 directional arrows, thus depicting l drift, not the actual path traversed by a bottle. ason for the selected groupings and the exclusion f bottles recovered after 30 days was the existence of the sand-shell beaches throughout the northwestern Mexico, and the possibility of bottles drifting shore, remaining intact, but not being found until some ter date.

s of drift, killometers per day, were determined coveries made within 15 days after release. In inances where several bottles were returned from a single the bottle or bottles adrift for the shortest time were used to determine rate of drift. Also, if two or more bottles, recovered from the same release, were adrift for the same period of time but had traveled different distances, these distances were averaged before determination of drift rate. Consequently, one directional arrow may represent the recovery of several bottles, and the speed an average speed.

Daily wind data from the climatological records published monthly by the U.S. Weather Bureau, now the National Weather Service, were used to depict prevailing wind conditions over the study area during each cruise (U.S. Department of Commerce 1962-1963a, 1962-1963b, 1962-1963c). This information was recorded at weather stations in Brownsville and Galveston, Tex., and New Orleans, La. Since the time required to complete each cruise varied, it was arbitrarily decided to construct resultant wind vectors for the time period between the first and last days of each cruise plus an additional 15 consecutive days. These data were converted to Beaufort units and incorporated into progressive vector analysis, the lengths of which measured in Beaufort units were divided by the total number of days to give a vector average for each period under consideration.

All drift bottle release and recovery data used in this report are on file in the National Oceanographic Data Center, Department of Commerce, Washington, D.C. 20235, under Ref. 78-0035.

Table 1.--Numbers of drift bottles released and recovered in the Gulf of Mexico within 0-15 and 16-30 days, by cruises, 1962 and 1963.

Cruise	Inclusive Dates	Total Deposited	Recoveries 0-15	Recoveries 16-30	% Recovered Within 30 days
1-62	Feb. 17-Feb. 27	651	25	12	6
2-62	Mar. 20-Mar. 27	697	27	53	11
3-62	Apr. 18-Apr. 26	690	33	39	10
4-62	May 18-May 22	525	26	11	7
5-62	June 18-July 1	691	32	25	8
6-62	July 18-Aug. 1	276	21	10	11
7-62	Sep. 7-Sep. 25	663	45	26	11
8-62	Oct. 16-Oct. 30	594	13	8	4
9-62	Nov. 14-Dec. 5	697	74	19	13
10-62	Dec. 4-Dec. 19	583	30	1	5
1962 Totals		6,067	326	204	9
1-63	Jan. 22-Feb. 5	305	13	5	6
2-63	Feb. 19-Mar. 9	203	14	20	17
3-63	Mar. 27-Apr. 6	254	21	61	32
4-63	Apr. 21-May 7	180	46	24	39
5-63	May 13-May 23	209	57	21	37
6-63	June 19-June 27	192	25	31	29
7-63	July 10-July 16	50	1	1	4
8-63	Aug. 17-Aug. 31	118	9	6	13
9-63	Sep. 22-Oct. 4	86	10	35	42
10-63	Oct. 20-Nov 4	111	0	13	12
11-63	Nov. 20-Dec. 1	88	1	9	11
1963 Totals		1,796	197	226	24

RESULTS AND DISCUSSION

Comparison of Ballasted and Unballasted Drift Bottles

Because of the use of two types of bottles, i.e., ballasted and unballasted, data were grouped by bottle type to determine if differences existed between rates of recovery (Table 2), direction of drift, and speed of drift.

Cruise values of percent recovery fluctuated from 22 to 54% between Cruise 1-62 and Cruise 6-63. Thereafter, values fluctuated from 0 to 76%, reflecting probably the reduced number of bottles released during this period (Table 1). It was readily apparent that in general fewer ballasted than unballasted bottles were recovered within 30 days after release (Table 2). For a comparison of direction and speed of ballasted and unballasted bottle drift, we arbitrarily selected 10 "test groups" for analysis, i.e., stations from which several ballasted and unballasted bottles were recovered within 15 days from a single release (Table 3).

The average direction of both types of bottles was usually similar. One exception was "test 8" in which several ballasted bottles moved southward down the coast, while several unballasted bottles moved northward up the coast. Average speeds were also generally similar with no definite indication that unballasted tles drifted at a greater rate than did unballasted bo

Surface Circulation

Over the 2-yr period, surface currents unde distinct directional shifts which were, in general, s between years. Because of this, specific mor although illustrated individually, have been grou irrespective of years: January-February; March June-July; August; and September-December.

January-February.—Currents during this n generally paralleled the northwestern Gulf coast, fl west off Louisiana and becoming southwest off (Fig. 2). Slight deviations from this pattern were parent in 1962 in two areas. Just west of the Miss River the flow was to the north and onshore, wher the south Texas coast there were indications of a shore countercurrent to the north.

Current velocities ranged from a low of 4 km/da high of 14 km/day. Greatest velocities (9-14 kr were observed in waters over the central portion o study area, i.e., off western Louisiana and eastern Te Lowest velocities occurred just west of the Miss River (5 km/day) and off south Texas (4 km/day), vicinity of Brownsville.

Table 2.—Comparison by cruise of recovery of ballasted and unballasted drift bottles within 30 days after release in the Gulf of Mexico

Cruise	Recoveries Ballasted	 Unballasted	 Total	Ballasted/ Total Recovered
1-62	8	29	37	22
2-62	27	53	80	34
3-62	17	55	72	24
4-62	9	28	37	24
5-62	21	36	57	37
6-62	7	24	31	23
7-62	19	52	71	27
8-62	7	14	21	33
9-62	50	43	93	54
10-62	9	22	31	29
1-63	9	9	18	50
2-63	17	17	34	50
3-63	31	51	82	38
4-63	25	45	70	36
5-63	33	45	78	42
6-63	25	31	56	45
7-63	0	2	2	0
8-63	3	12	15	20
9-63	34	11	45	76
10-63	8	5	13	62
11-63	7	3	10	70
Totals	366	587	953	38

Table 3.—Comparison of the direction and speed of ballasted (B) and unballasted (U) bottles recovered within 15 days after release in the Gulf of Mexico.

Test	Type Bottle	Number Recovered	Direction (True)		Speed (km/day)	
			Range	Average	Range	Average
#1	B	4	--	276°	--	4.6
	U	6	230°-276°	268°	1.9.-4.6	4.1
#2	B	4	007°-016°	013°	3.7-18.5	9.3
	U	5	347°-007°	357°	3.7-15.7	11.7
#3	B	6	244°-359°	263°	0.9-3.9	1.7
	U	6	--	244°	--	1.1
#4	B	6	204°-215°	207°	17.0-21.1	19.8
	U	2	204°-205°	204°	18.3-19.1	18.7
#5	B	5	--	339°	5.9-6.3	6.1
	U	4	331°-339°	334°	2.6-6.3	3.7
#6	B	5	292°-307°	302°	2.4-4.8	4.3
	U	6	292°-317°	305°	2.9-9.3	5.0
#7	B	3	--	298°	--	6.3
	U	5	--	298°	6.3-8.3	7.0
#8	B	5	180°-195°	187°	5.6-6.5	6.1
	U	5	195°-009°	334°	5.6-26.8	10.7
#9	B	4	--	291°	25.9-38.9	32.4
	U	3	--	291°	5.9-38.9	20.0
#10	B	3	336°-354°	346°	4.4-7.9	6.7
	U	4	341°-012°	360°	8.3-14.6	9.8

ltant wind vectors for the cruise periods revealed ces between areas in the northwestern Gulf as ell as differences between months. In January 1963, at New Orleans were generally northerly or off- those at Galveston northeasterly or alongshore, nd those at Brownsville southeasterly or onshore. This irculation pattern of winds may account for the absence veries of bottles released east of Galveston.

ebruary 1962 and 1963 winds were generally imilar over the entire study area, i.e., east to southeast owing west alongshore at New Orleans and Galveston shore at Brownsville. Strongest winds occurred at ville in both years and probably accounted for the educed rate of alongshore flow of surface waters bserved in that area.

March-May.—Drift bottle movements indicated a ransitional period for surface currents in the study area both years with several distinct features (Figs. 3, t, the flow of surface waters off Louisiana was redominately to the west in March of both years, but as me progressed, the flow direction generally shifted to rth and became onshore in May. This onshore ent was more pronounced in May 1962 than in ay 1963 when some east to west movement was still apparent. Apparent monthly differences in the timing of akdown of the dominant east to west movement n years may be accounted for by the difference in ruise dates between years or may reflect real yearly differences. Associated with this dominant flow off Louisiana was a generally weak northward onshore movement of nearshore waters just west of the Mississippi River.

The second prominent feature during this period was the movement of waters off the south Texas coast. Recoveries during both years indicated an area of convergence of currents. Furthermore, as the season progressed, this arc of convergence moved northward up the Texas coast until the flow of surface waters became almost directly onshore. In May 1963, however, this pattern can only be inferred due to the paucity of drift bottle releases off the south Texas coast.

The third distinct feature of the circulation pattern was the indication of the presence of an oceanic surface current that existed in waters beyond the continental shelf. This was particularly apparent in March of both years and April 1962 when several bottles deposited on the edge of the shelf apparently moved against (straight line trajectory) prevailing shelf currents. From this set of data, it appeared that in the surface waters three current systems may have been present in the study area: a nearshore countercurrent, a shelf current, and an oceanic current.

Current velocities varied depending on location within the study area. Speeds of the dominant east to west drift off Louisiana ranged between 7 and 14 km/day whereas the weak onshore current just west of the Mississippi River ranged from 1 to 3 km/day. Within the area of convergence off Texas, speeds ranged from 3 to 17 km/

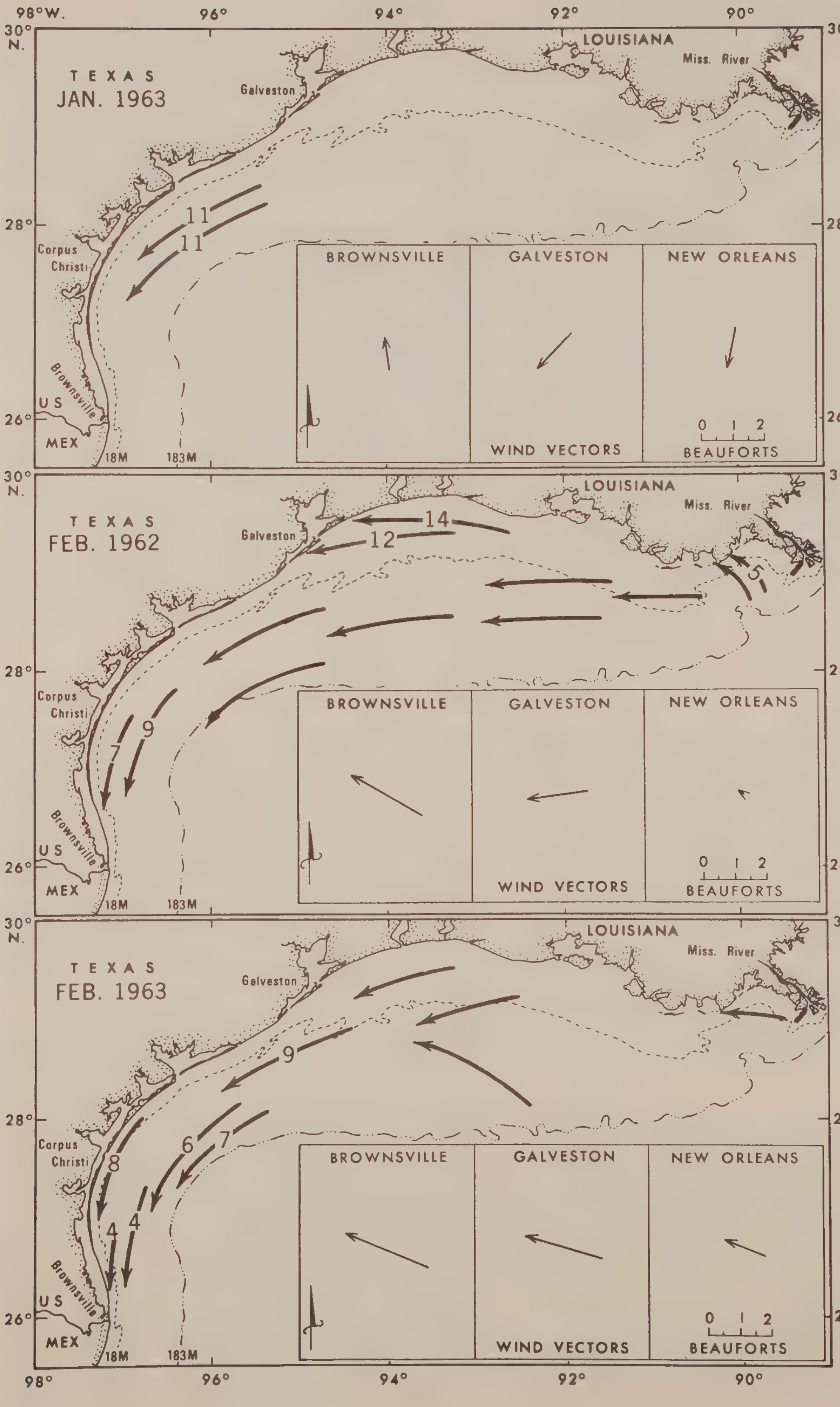
98°W.
96°
94°
92°
90°
30° N.
28°
26°
TEXAS
JAN. 1963
Galveston
LOUISIANA
Miss. River
Corpus Christi
Brownsville
US
MEX
18M
183M
11
11
BROWNSVILLE
GALVESTON
NEW ORLEANS
WIND VECTORS
0 1 2
BEAUFORTS
TEXAS
FEB. 1962
14
12
5
9
7
TEXAS
FEB. 1963
9
6
7
8
4
4
98°

Figure 2. Su face circulati deduced from coveries bottles rel January 1963 a February 1962 a 1963 in the western Mexico. (indicate directi of flow; numb indicate km/day).

ing was employed later for the shortnose sturgeon.

RKNESS, W. J. K., and J. R. DYMOND.
1961. The lake sturgeon. Ont. Dep. Lands Forests, 97 p.

Acipenser brevirostrum, with its range, is included in a list of the sturgeons of the world.

DEBRAND, S. F., and W. C. SCHROEDER.
1928. Fishes of Chesapeake Bay. Bull. Bur. Fish. 43, 366 p.

The shortnose sturgeon is discussed from published accounts and a specimen taken off Provincetown, Mass., now in the Museum of Comparative Zoology, Cambridge, Mass., is described.

HOFF, J. G.
1965. Two shortnose sturgeon, *Acipenser brevirostris*, from the Delaware River, Scudder's Falls, New Jersey. Bull. N.J. Acad. Sci. 10:23.

A ripe shortnose sturgeon of each sex was examined.

LAND, B. F., Jr., and G. F. YELVERTON.
1973. Distribution and biological studies of anadromous fishes offshore North Carolina. N.C. Dep. Nat. Econ. Res., S. S. R. No. 24, 132 p.

Between 1968 and 1971, eight shortnose sturgeon were caught offshore between Cape Fear, N.C., and Cape Henry, Va.

HOLLY, M.
1936. Pisces 4. Ganoidei. Das Tierreich (67), Berlin, 65 p.

A systematic review of the sturgeon family.

HOVEY, H. C.
1883. The sturgeon fishery. Bull. U.S. Fish Comm. 4:346-348.

Information on the sturgeon fishery of the Delaware River is given along with the sturgeon's preparation for market and the table.

JENKINS, R. E., and J. A. MUSICK.
In press. Fishes. *In* D. Linzey (editor), Threatened and endangered plants and animals of Virginia. Va. Polytech. Inst.

Shortnose sturgeon endangered animal of Virginia.

JEROME, W. C., Jr., A. P. CHESMORE, and C. O. ANDERSON, Jr.
1968. A study of the marine resources of the Parker River-Plum Island Sound Estuary. Division of Marine Fisheries, Department of Natural Resources, The Commonwealth of Massachusetts, 79 p.

An Atlantic and a shortnose sturgeon were taken by Bill Sibley on the *Peggybell* in Ipswich Bay near the mouth of Plum Island Sound in 1966. A picture of the shortnose sturgeon is included.

JORDAN, D. S.
1876. Manual of the vertebrates of the northern United States, including the district east of the Mississippi River, and north of North Carolina and Tennessee, exclusive of marine species. 1st ed. Jansen, McClurg and Co., Chicago, 342 p.

A brief description and range is given.

1878, 1880, 1884. Manual of the vertebrates of the northern United States, including the district east of the Mississippi River, and north of North Carolina and Tennessee, exclusive of marine species. 2d, 3rd, 4th ed. Jansen, McClurg & Co., Chicago.

A brief description and range is given.

1886. Notes on fishes collected at Beaufort, North Carolina, with a revised list of the species known from that locality. Proc. U.S. Natl. Mus. 9:25-30.

Shortnose sturgeon is included in the list.

1887. A catalogue of the fishes known to inhabit the waters of North America north of the Tropic of Cancer, with notes on the species discovered in 1883 and 1884. Rep. U.S. Comm. Fish. 1885:789-973.

The shortnose sturgeon is listed.

1897, 1899, 1904. A manual of the vertebrate animals of the northern United States including the district north and east of the Ozark Mountains, south of the Laurentian Hills, north of the southern boundary of Virginia, and east of the Missouri River, inclusive of marine species. 7th, 8th, 9th ed. A. C. McClurg and Co., Chicago.

A brief description and range is given.

1929. Manual of the vertebrate animals of the northeastern United States inclusive of marine

species. 13th ed. World Book Company, N.Y., 446 p.

Description and range are given.

JORDAN, D. S., and B. W. EVERMANN.

1896a. A checklist of the fishes and fish-like vertebrates of North and Middle America. Rep. U.S. Comm. Fish. 1894:207-584.

The range of the shortnose sturgeon is given.

1896b. The fishes of North and Middle America. Bull. U.S. Natl. Mus. 47, 3313 p.

The shortnose sturgeon is described with its range. The specimen described is from South Carolina.

1904. American food and game fishes. Doubleday, N.Y., 572 p.

The range is from Texas to Cape Cod and the habits are similar to the common Atlantic.

1937. American food and game fishes. Doubleday, N.Y., 512 p.

The shortnose sturgeon is included with a brief description and distribution.

JORDAN, D. S., B. W. EVERMANN, and H. W. CLARK.

1930. Check list of the fishes and fishlike vertebrates of North and Middle America, north of the northern boundary of Venezuela and Colombia. Rep. U.S. Comm. Fish. 1928 (Part 2), 670 p.

Shortnose sturgeon is included in the checklist.

JORDAN, D. S., and C. H. GILBERT.

1882. Synopsis of the fishes of North America. Bull. U.S. Natl. Mus. 16, 1018 p.

A description and range is given.

KENDALL, W. C.

1908. Fauna of New England. 8. List of the Pisces. Occas. Pap. Boston Soc. Nat. Hist. 7, 152 p.

The shortnose sturgeon is recorded in New England.

KILBY, J. D., E. CRITTENDEN, and L. E. WILLIAMS.

1959. Ichthyological notes: Several fishes new to Florida freshwaters. Copeia 1959:77-78.

The shortnose sturgeon was incorporated in Florida's faunal list in 1896. In recent years authors have been inclined to exclude Florida from the range of the species. However, adult shortnose sturgeon was taken in 194 commercial seine from the St. John's River and donated to the University of Florida collections.

KIRSCH, P. H., and M. W. FORDICE.

1889. A review of the American species of sturg (Acipenseridae). Proc. Acad. Nat. Sci. Ph 41:245-257.

A review of the American Acipenseridae, ba on species belonging to the Museum of the U versity of Indiana.

KOSKI, R. T., E. C. KELLEY, and B. E. TU BOUGH.

1971. A record-sized shortnose sturgeon from the Hudson River. N.Y. Fish Game J. 18:75.

A shortnose sturgeon measuring 932 mm in t length was caught in January 1970 in the Hudson River (from Tappan Zee Bridge to B Mountain Bridge).

LEACH, G. C.

1920. Artificial propagation of sturgeon. Par Review of sturgeon culture in the Un States. Rep. U.S. Comm. Fish. 1919:3-5.

A review of the attempts and drawbacks sturgeon culture in the United States provided. Species were not mentioned; however, this material is applicable to the sh nose sturgeon.

LEIM, A. H., and L. R. DAY.

1959. Records of uncommon and unusual fi from eastern Canadian waters, 1950-1958. Fish. Res. Board Can. 16:503-514.

The first authentic Canadian record is given the shortnose sturgeon. The specimen, 69 long, was caught by the MV *Harengus* in the Long Reach, Saint John River, N.B., on 20 Ma 1957. Identification was made by V. Vladykov.

LEIM, A. H., and W. B. SCOTT.

1966. Fishes of the Atlantic Coast Canada. Bull. Fish. Res. Board Can. 155, 485 p.

A general description and natural history of shortnose sturgeon is given.

LELAND, J. G., II.

1968. A survey of the sturgeon fishery of Sc Carolina. Contrib. Bears Bluff Labs. 47, 27

The history and present situation of the sturgeon fishery of South Carolina is presented. Individual species were not mentioned; however, it is stated that there is practically no market for small sturgeon (3-12 pounders) and that these are not taken in the sturgeon nets. They do become enmeshed in shad nets and are killed by the shad fisherman. These small sturgeon may include shortnose sturgeon.

JEUR, C. A.
1818. Description of several species of Chondropterygious fishes of North America, with their varieties. Trans. Am. Philos. Soc. 1:383-395.

The author gives the original description of the species, with three varieties, from specimens caught in the Delaware River.

MacCALLUM, G. A.
1921. Studies in helminthology. Zoopathalogica 1:137-284.

Three individuals of the trematode *Nitzschia superba* were found on the gills of a male and female shortnose sturgeon from the New York Aquarium on 22 September 1915.

NIN, E.
1959. Répartition actuelle de Acipenséridés. Revue Trav. Inst. (Sci. Tech.) Pêch. Marit. 23:277-285.

A distribution of the Acipenseridae is presented.

1963. Notes sur la répartition, la biologie et particuliérement la croissance de l'*Acipenser brevirostris* LeSueur 1817. Nat. Can. (Que.) 90:87-96.

Magnin presents data on the age, length, and biology of 10 specimens from the St. John River near Fredericton, N.B.

1964. Croissance en longeur de trois esturgeons d'Amérique du Nord: *Acipenser oxyrhynchus* Mitchill, *Acipenser fulvescens* Raffinesque, et *Acipenser brevirostris* LeSueur. Verh. Int. Verein. Theor. Angew. Limnol. 15:968-974.

A growth comparison of three eastern North American species is presented.

SMANN, W. H.
1958. A checklist of fishes of the Virginia waters of Chesapeake Bay and its tidal tributaries. Va. Fish. Lab., Fin Fish Prog. Rep. 60, 14 p.

The shortnose sturgeon is on the checklist.

McALLISTER, D. E.
1960. List of the marine fishes of Canada. Bull. Natl. Mus. Can. 168, 8 p.

Shortnose sturgeon is included in the list.

1970. Rare and endangered Canadian fishes. Can. Field-Nat. 84:5-8.

At this time, shortnose sturgeon is known only in the lower St. John River, N.B., from the mouth to Gagetown. Increasing pollution and a hydroelectric dam may be of significance in their survival.

McALLISTER, D. E., and C. G. G. GRUNCHY.
1977. Status and habitats of Canadian fishes in 1976. *In* T. Mosquin (editor), Canada's threatened species and habitats, 185 p. Canadian Nature Federation, Ottawa.

Listed shortnose sturgeon as rare with moderate population in St. John River, N.B. Unanswered questions on its spawning and population trends.

McCLEAVE, J. D., and S. M. FRIED.
1974. Three unusual shortnose sturgeon (*Acipenser brevirostrum*) from Montsweag Bay, Me. Can. Field-Nat. 88:359-360.

Three unusual specimens were captured: one with only one barbel, one with forked barbels, and one bilaterally blind. The blind specimen appeared to be in good condition and it is noted that blind, dark, healthy shortnose sturgeon have also been observed.

McCLEAVE, J. D., S. M. FRIED, and A. K. TOWT.
1977. Daily movements of shortnose sturgeon, *Acipenser brevirostrum* in a Maine estuary. Copeia 1977:149-157.

The daily summer movements of 15 shortnose sturgeon in Montsweag Bay were studied by ultrasonic telemetry.

McLANE, W. M.
1955. Fishes of the St. John's River System. Ph.D. Thesis, Univ. Fla. Tallahassee, 367 p.

Both common and shortnose sturgeon are reported to be extremely rare on the Atlantic coast of Florida.

MEEHAN, W. E.
1896. Fish, fishing and fisheries of Pennsylvania. Rep. State Comm. Fish. 1895, 245 p.

Chapter 5 is entitled *The Sturgeon Fisheries of the Delaware.*

1910. Experiments in sturgeon culture. Trans. Am. Fish. Soc. 39:85-91.

The shortnose sturgeon used in the experiment were from the Delaware River. The experiment showed that shortnose sturgeon can be carried from year to year in ponds 200 or more feet long and proportionately wide and deep, and their eggs can be taken safely in sufficient number to warrant fish cultural work.

METH, F. F.
1971. Ecology of St. John River Basin II. Catalogue of estuary fish species for the Saint John River. Environment Canada (Mimeogr. rep.), 28 p.

Shortnose sturgeon recorded for the Saint John River.

1972. Ecology of Saint John River Basin V. Status of estuary fisheries. Environment Canada (Mimeogr. rep.), 6 p.

Shortnose sturgeon recorded for the Saint John River.

1973. Sport and commercial fisheries of the St. John estuary. Rep. St. John River Basin Board 76:1-70.

The paper includes a general account of the shortnose sturgeon.

MIGDALSKI, E. C., and G. S. FICHTER.
1976. The fresh and salt water fishes of the world. Alfred A. Knopf, N.Y., 316 p.

Its range and differentiation from the common sturgeon are given.

MILLER, R. R.
1972. Threatened freshwater fishes of the United States. Trans. Am. Fish. Soc. 101:239-252.

Connecticut, Delaware, Maryland, Massachusets, New Jersey, and Pennsylvania list shortnose sturgeon as being an endangered species.

MONTPETIT, A. N.
1897. Les poisson d'eau douce du Canada. Montreal, 553 p.

The shortnose sturgeon is erroneously reported as occurring in the St. Lawrence and lacs St. Pierre, St. Louis, and St. Froid.

NEW YORK MARKET INDEX AND JOURNAL.
1880. Report for 1879 and 1880 of the sale of fish in Fulton Market, New York. Bull. U.S. F
Comm. 3, 426 p.

It is reported that 70,633 pounds of sturg
were sold between March 1878 and March 1
and 68,858 pounds between March 1879 and March 1880. Species and size were not mentioned; therefore, shortnose sturgeon may be
cluded in the sale.

NICHOLS, J. T.
1918. Fishes of the vicinity of New Y
City. Am. Mus. Nat. Hist. Handb. Ser., No
118 p.

A small sturgeon, *Acipenser brevirostris*, t
reaches a length of 2 ft occurs in the New Y
City area.

NICHOLS, J. T., and C. B. BREDER, JR.
1927. The marine fishes of New York and southern New England. Zoologica (N.Y.) 9, 192 p.

The shortnose sturgeon is briefly described w
its distribution.

OFFICE OF ENDANGERED SPECIES AND INT
NATIONAL ACTIVITIES.
1973. Threatened wildlife of the U.S. U.S. Dep. Inter. Res. Publ. 114, 289 p.

This is a revision of Resource Publication 34 (1966) (see Committee on Rare and Endangered Wildlife Species (1966)).

PERLMUTTER, A.
1961. Guide to marine fishes. New York U
Press, 431 p.

A short description of the color, distribution, size, general information, and economic im
tance of the shortnose sturgeon is provided

PRATT, H. S.
1935. A manual of land and fresh water verteb
animals of the United States (exclusive
birds). 2d ed. P. Blakiston's Son and Co., Inc., Phila., 416 p.

A brief description of the species is given.

PROVANCHER, L'ABBÉ.
1876. Faune canadienne. Les poissons. Nat. C
(Que.) 7:361-363.

Fortin's erroneous record of the shortnose s
geon in the St. Lawrence River is cited.

RICHARDSON, J.
1836. Fauna boreali-Americana, or the zoology of the northern parts of British America. Part III. The fish. Richard Bentley, Lond., 278 p.

The shortnose sturgeon is described.

ROSTLUND, E.
1952. Freshwater fish and fishing in native North America. Univ. Calif. Press, Berkeley, 248 p.

The range is given for the shortnose sturgeon.

DER, R. A.
1888. The sturgeons and sturgeon industries of the eastern coast of the United States, with an account of experiments bearing upon sturgeon culture. Bull. U.S. Fish Comm. 8:231-328.

This is the first diagnosis of the species since LeSueur's original description in 1817. From specimens caught in the Delaware River, the author gives distinctive characters by which the species might be recognized. He also notes that the species is always small, confirmed by the fact that sexual maturity is reached much earlier than in the common form.

HAEFER, R. H.
1967. Species composition, size and seasonal abundance of fish in the surf waters of Long Island. N.Y. Fish Game J. 14:1-46.

One shortnose sturgeon was caught off Fire Island, N.Y., in 1962.

HRENKELSEN, R.
1938. Field book of the freshwater fishes of North America north of Mexico. Putnam, N.Y., 312 p.

A general account of the shortnose sturgeon is presented.

HWARTZ, F. J., W. W. HASSLER, J. W. REINT-ES, and M. W. STREET.
1975. Endangered and threatened plants and animals of North Carolina: Marine fishes. Proceedings of the symposium on endangered and threatened biota of North Carolina. 1. Biological concerns. N.C. State Mus. Nat. Hist., p. 250-264.

These are unconfirmed reports of the shortnose sturgeon from offshore; once sporadically known from Albemarle and Pamlico Sounds, and other North Carolina waters, but today it is believed extirpated.

HWARTZ, F. J., and G. W. LINK, JR.
1976. Status of Atlantic, *Acipenser oxyrhynchus*, and shortnose, *Acipenser brevirostrum*, sturgeons in North Carolina (Pisces, Acipenseridae). ASB (Assoc. Southeast. Biol.) Bull. 23:94.

The shortnose sturgeon is believed extinct in North Carolina.

SCOTT, W. B.
1954, 1967. Freshwater fishes of eastern Canada. 1st, 2d ed. Univ. Toronto Press.

Distribution in Canada for the shortnose sturgeon and variation from the common sturgeon is provided.

SCOTT, W. B., and E. J. CROSSMAN.
1959. The freshwater fishes of New Brunswick: A checklist with distributional notes. R. Ont. Mus. Life Sci. Contrib. 51, 37 p.

The only shortnose sturgeon caught in Canada up to this date is Vladykov's catch in 1957 in the St. John River.

1973. Freshwater fishes of Canada. Bull. Fish. Res. Board Can. 184, 966 p.

A more detailed description and natural history than Leim and Scott (1966) is given. It is noted that the largest shortnose sturgeon on record was a 1,006-mm female from the Connecticut River.

SCOTT, W. B., and M. G. SCOTT.
1965. A checklist of Canadian Atlantic fishes with keys for identification. R. Ont. Mus. Life Sci. Contrib. 66, 106 p.

The shortnose sturgeon is included in the list and a key to the family Acipenseridae is provided.

SLASTENENKO, E. P.
1958. The freshwater fishes of Canada. Kiev Printers, Toronto, 383 p.

A general account of the shortnose sturgeon.

SMITH, H. M.
1891. Report on the fisheries of the South Atlantic states. Bull. U.S. Fish Comm. 11:269-356.

Size is not reported; therefore, shortnose sturgeon may have been caught. The sturgeon fishery is noted as having the most noticeable decline in the river fisheries of the South Atlantic States during the past decade. A decrease of 80% in the yield of sturgeon during the past 10 yr is reported.

1892. Economic and natural-history notes on fishes of the northern coast of New Jersey. Bull. U.S. Fish Comm. 12:365-380.

Only the common sturgeon is cited. However, in its discussion it is mentioned that small fish called "moose" are sold whole; the name appears to be a corruption of "mammoose" which is current in Delaware Bay, and is applied to young fish that are too small to dress and are usually sold whole. These small sturgeon may be the shortnose species.

1894. A statistical report of the fisheries of the middle Atlantic states. Bull. U.S. Fish Comm. 14:339-467.

The common sturgeon is included in a list of the important fishes of the middle Atlantic states. However, the species is broken into three groups: sturgeon, mammoose—Delaware River, and moose (young)—New Jersey. The latter two groups most likely include the shortnose sturgeon.

1897. Fishes found in the vicinity of Woods Hole. Bull. U.S. Fish Comm. 17:85-111.

The shortnose sturgeon is found in company with the common sturgeon but is less numerous than the latter. It is taken in traps.

1907. The fishes of North Carolina. N.C. Geol. Econ. Surv. 2, 445 p.

Actual records of its occurrence in North Carolina are rare.

1914. Passing of the sturgeon. Rep. U.S. Comm. Fish. 1913:66-67.

A review of the overfishing of the sturgeon, which is applicable to the shortnose sturgeon.

1915. Report of the commissioner of fisheries for the fiscal year ended June 30, 1914. Sturgeon Fishery of Delaware River. Rep. U.S. Comm. Fish. 1914, 81 p.

Some sturgeon with large roe are caught as late as September, but a large portion of such fish are of the smaller species (*A. brevirostrum*), locally called "bottlenose."

SMITH, H. M., and B. A. BEAN.
1899. List of fishes known to inhabit the waters of the district of Columbia and vicinity (1898). Bull. U.S. Fish Comm. 18:179-187.

Shortnose sturgeon are found in this area but are not as abundant as the common sturgeon and have undergone the same decrease in recent years. It is probably not recognized by fis men as a different species.

STORER, D. H.
1846. A synopsis of the fishes of No America. Mem. Am. Acad. Sci., New. 2(7):253-550.

A brief description of the shortnose sturgeo presented.

SUMNER, F. B., R. C. OSBURN, and L. J. COLE
1911. A biological survey of the waters of Wo Hole and vicinity. Part II. Bull. U.S. Bur. Fish. 31:549-794.

The common sturgeon is listed, however shortnose sturgeon is included in its references. When listing parasites of the common sturgeon, it is noted that the spiny-headed wo *Echinorhynchus attenuatus*, is listed for shortnose sturgeon.

SYRYABINA, E. S.
1974. Gel'minty osetrovykh ryb (Acipenserida Bonaparte, 1831). Moscow, USSR; Izdatel' "Nauka," 168 p.

This is a monograph on the helminth fauna o acipenserid fish of the world based on data f the literature and on the author's examina of his own collection of eight fish from waters o the U.S.S.R. The 22 species of Acipenseri known are parasitized by 95 helminth spe 27 of which are specific to this group.

TAUBERT, B. D., and R. J. REID.
1978. Observations of the shortnose sturgeon (*penser brevirostrum*) in the Holyoke pool of the Connecticut River, Massachusetts. Progres Report to NEUSC. Mass. Coop. Fish U Amherst, Mass., 14 p.

Spawning site and larvae description are identified in the Connecticut River.

TOWER, W. S.
1908. The passing of the sturgeon: A case of the paralleled extermination of a species. Pop. Mon. 73:361-371.

A history of the sturgeon fishery and the termination of the sturgeon is provided. Spe are not mentioned.

TOWNSEND, C. H.
1901a. Statistics of the fisheries of the mi

Atlantic states. Rep. U.S. Comm. Fish. 1900:195-310.

Catch and market statistics for sturgeon in New York, New Jersey, Pennsylvania, Delaware, Maryland, and Virginia are given. Species are not mentioned.

1901b. Statistics of the fisheries of the New England states. Rep. U.S. Comm. Fish. 1900:311-386.

Catch and market statistics for sturgeon in Maine, Massachusetts, and Connecticut are given. Since species are not mentioned, the shortnose sturgeon is probably included.

ACY, H. C.
1906. A list of the fishes of Rhode Island. Rep. Comm. Inland Fish. R.I. 36, 176 p.

The shortnose sturgeon is briefly described along with its occurrence in Rhode Island.

TES, R. W.
1960. An oceanographic and biological reconnaissance of Kennebecasis Bay and St. John River Estuary. J. Fish. Res. Board Can. 17:377-408.

Additional occurrence of shortnose sturgeon is recorded in the St. John River, N.B.

UITT, R. V., T. H. BEAN, and H. W. FOWLER.
1929. The fishes of Maryland. Bull. Md. Conserv. Dep. 3, 120 p.

A general account of the shortnose sturgeon is given.

LER, P. R., and O. LUGGER.
1876. List of fishes of Maryland. Rep. Comm. Fish. Md. 1876:67-176.

The shortnose sturgeon inhabits the Potomac River. This individual, represented by a few strips of skin is USNM #26273. It was collected 19 March 1876.

U.[illegible]. CONGRESS.
1973. House of Representatives Endangered Species Act of 1973. Public Law 93-205, December 28, 1973.

Shortnose sturgeon are included on the list.

VLADYKOV, V. D., and G. BEAULIEU.
1951. Études sur l'esturgeon (Acipenser) de la province de Québec. II. Variations du nombre de branchiospines sur le premier arc branchial. Nat. Can. (Que.) 78:129-154.

The shortnose sturgeon is included in a detailed account of gill rakers for three western Atlantic sturgeon species.

VLADYKOV, V. D., and J. R. GREELEY.
1963. Order Acipenseroidei. *In* Fishes of the Western North Atlantic. Mem. Sears Found. Mar. Res. 1(3), 630 p.

A description and natural history of the shortnose sturgeon, based on a total of 109 specimens, is given. An extensive bibliography is included.

WALDEN, H. T.
1964. Familiar freshwater fishes of America. Harper and Row, N.Y., 282 p.

A brief description and range is given.

WHITWORTH, W. R., P. L. BERRIEN, and W. T. KELLER.
1968. Freshwater fishes of Connecticut. Conn. State Geol. Nat. Hist. Surv. Bull. 101, 134 p.

The shortnose sturgeon is briefly described along with its natural history.

WILDER, B. G.
1875. Notes on the North American ganoids, *Amia, Lepidosteus, Acipenser, Polydon.* Proc. Am. Assoc. Adv. Sci. 1875:151-196.

The brains of three Acipenser species (*A. oxyrhynchus, A. rubicundus,* and one undetermined) were compared with the brains of other genera. Since size was not indicated, *A. brevirostrum* could have been the undetermined species.

YARROW, H. C.
1877. Notes on the natural history of Fort Macon, North Carolina, and vicinity. No. 3. Fishes. Proc. Acad. Nat. Sci. Phila. 29:203-218.

Shortnose sturgeon are said to be abundant in the North, New, and Neuse Rivers.

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Annotated Bibliography and Subject Index on the Shortnose Sturgeon, *Acipenser brevirostrum*

James G. Hoff

April 1979

U.S. DEPARTMENT OF COMMERCE
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National Oceanic and Atmospheric Administration
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Annotated Bibliography and Subject Index on the Shortnose Sturgeon, *Acipenser brevirostrum*

JAMES G. HOFF[1]

ABSTRACT

A bibliography that consists of 165 references on the classification, distribution, abundance, life history, and ecology of the shortnose sturgeon, *Acipenser brevirostrum*. Brief annotations and a subject index are included for this rare and endangered species.

INTRODUCTION

This bibliography consists of 165 references on the atics, distribution, life history, and ecology of the se sturgeon, *Acipenser brevirostrum* LeSueur. Arrangement of the references is alphabetical by uthor's surname. With multiple authors, the entry is nly under the senior author's name. Each author's are listed chronologically by year of publication nd those published in the same year are given lphabetical sequence by title. Anonymous articles are by the name of the journal or the originating

Brief annotations of the contents of the publications nat apply to the shortnose sturgeon and its scientific re given. This annotation is not done to make udgments of the papers but to give clearer descriptions of the contents than can be obtained from their ti-

e task of examining the vast number of scattered eferences in the ichthyological literature, I have received d from many individuals. Thanks go to the librarians Marine Biological Laboratory at Woods Hole, and to the librarians at the Museum of Comarative Zoology at Harvard University. My inebtedness to those persons and institutions is great. I ledge the help I received from Brian Kinnear and adswell, comembers of the shortnose sturgeon enangered species recovery team.

I wish to give special thanks to the Southeastern husetts University biology students who helped throughout the preparation of this bibliography, notably usan Faria, James Hoff, Jr., and Michael Murphy. And I thank the typist, Rita Sasseville.

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5. Statistics of the fisheries of the New England states. Rep. U.S. Comm. Fish. 1904:245-326.

Catch and market statistics for sturgeon in Maine, New Hampshire, Massachusetts, and Connecticut are given. Since species are not mentioned, the shortnose sturgeon is probably included.

ANONYMOUS.
1975. Threatened wildlife of the United States. U.S. Fish Wildl. Serv. Resour. Publ., 289 p.

The shortnose sturgeon is listed as being endangered and a recommendation was made by the Department of the Interior to locate and protect shortnose sturgeon spawning sites.

APPY, R. G., and M. J. DADSWELL.
1978. Parasites of *Acipenser brevirostrum* LeSueur and *Acipenser oxyrhynchus* Mitchill (Osteichthyes: Acipenseridae) in the Saint John River Estuary, N. B., with a description of *Caballeronema pseudoargumentosus* sp. n., (Nematoda: Spirurida). Can. J. Zool. 56:1382-1391.

Shortnose, juvenile Atlantic, and mature Atlantic sturgeons have distinct parasite faunas which may reflect their contrasting life histories.

ATZ, J. W., and C. L. SMITH.
1976. Hermaphrodism and gonadal teratoma-like growths in sturgeon (*Acipenser*). Bull. South. Calif. Acad. Sci. 75:119-126.

An adult *Acipenser brevirostrum* from the Hudson River exhibited ovotestes. This teratoma-like structure may have been the result of the abnormal development of a parthogenetic or self-fertilized egg.

BAIRD, S. F.
1873. List of fishes collected at Woods Hole. Rep. U.S. Comm. Fish. 1871-1872:823-827.

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astern Massachusetts University, North Dartmouth, MA

The shortnose sturgeon was collected in 1871 at Woods Hole. A complete collection of the 121 fish species was deposited in the U.S. National Museum.

BEAN, T. H.

1897. Notes upon New York fishes received at the New York Aquarium, 1895-1897. Bull. Am. Mus. Nat. Hist. 9:327-375.

A single shortnose sturgeon from Gravesend Bay was brought to the aquarium on 13 May 1896. It had taken food regularly, and was living (7 December 1897). The species proved to be well adapted to aquarium life.

1901. Catalogue of the fishes of Long Island. Rep. Forest Fish Game Comm. N.Y. State 1900:251-260.

Range and differentiation from the common sturgeon is provided.

1902. Food and game fishes of New York. Rep. Forest Fish Game Comm. N.Y. State 7:251-260 .

The shortnose sturgeon is only positively recognized in the Delaware and Gravesend Bay. In 1817, it was brought in the shad season to Philadelphia and sold from 25 to 75 cents each.

1904. Catalogue of the fishes of New York. Bull. N.Y. State Mus. 60, 784 p.

Includes an erroneous description of shortnose sturgeon spawning and feeding habits, misquoted directly from Ryder (1888).

BERG, L. S.

1904. Zyr systmatik der Acipenseridae. Zool. Anz. 27:665-667.

A taxonomic account of the shortnose sturgeon is given.

1940. Classification of fishes both recent and fossil. Applied Scientific Research Corporation of Thailand, Bangkok (1965):346-517.

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BERTIN, L.

1939. Revision des Stromiatiformes (Téléostéens, Isopondyles) du muséum. Bull. Mus. Hist. Nat., Paris 2(11):378-382.

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BIGELOW, H. B., and W. C. SCHROEDER.

1936. Supplemental notes on fishes of the Gu
Maine. Bull. U.S. Bur. Fish. 48:319-348.

A 30-inch specimen, taken at Province
about 1907, now in the collection at
Museum of Comparative Zoology, was th
reliable record for the Gulf of Maine.
record was omitted from "Fishes of the Gu
Maine" (Bigelow and Welsh 1925).

1953. Fishes of the Gulf of Maine. U.S.
Wildl. Serv., Fish. Bull. 53, 577 p.

A description, life history, and coastal di
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quoit, Mass.; from the Hudson River,
from the Delaware Bay and River; and
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BLAIR, W. F., A. P. BLAIR, P. BRODKORB,
CAGLE, and G. A. MOORE.

1957. Vertebrates of the United States.
ed. McGraw-Hill Book Co., N.Y., 616 p.

A brief description and range for
brevirostrum.

BOWERS, G. M.

1907. Statistics of the fisheries of the New Eng
states for 1905. Rep. U.S. Comm. Fish.
93.

Catch and market statistics for sturgeo
Maine, Massachusetts, and Connectic
given. Since species are not mentione
shortnose sturgeon is probably included.

BOYLE, R. H.

1969. The Hudson River, a natural and unn
history. W. W. Norton and Co., N.Y., 304

According to the Interior Department, all
catches of shortnose sturgeon, except
Florida specimen, have been from the Hu
Occasional specimens exceed the pu
record size in the scientific literature.
and again in 1969, a hermaphroditic spec
was caught. Information on their nat
history, caviar preparation, cooking, a
mand at aquariums is provided.

BREDER, C. M., Jr.

1938. The species of fish in New Yor
bor. Bull. N.Y. Zool. Soc. 41(1):26-28.

The shortnose sturgeon is included in
fishes inhabiting the New York harbor.

1948. Field book of marine fishes of the Atlantic coast, from Labrador to Texas. G. P. Putnam's Sons, N.Y., 332 p.

The shortnose sturgeon is briefly described with its range.

BRICE, J. J.

98. A manual of fish-culture, based on the methods of the United States Commission of Fish and Fisheries. Rep. U.S. Comm. Fish. 1897:1-340.

Experimental work indicates that there are no insurmountable obstacles in the way of extensive artificial propagation, although the work presents some unusual difficulties.

UMPUS, H. C.

98. The breeding of animals at Woods Hole dur-ng the months of June, July and August. Science 8:850-858.

Acipenser brevirostrum was occasionally taken in June, the females bearing ripe eggs.

HUTE, W. H.

4. Guide to the John G. Shedd Aquarium. 4th ed. Shedd Aquarium, Chicago, 236 p.

The shortnose sturgeon is one of the species held in the Shedd Aquarium.

OBB, S. N.

0. The sturgeon fishery of the Delaware River nd Bay. Rep. U.S. Comm. Fish. 1899:369-380.

Both species are found in the Delaware River, but only the common sturgeon is put to commercial use. *Acipenser brevirostris* rarely exceeds 3 ft and therefore is not gilled. Some are taken at the shore seine fisheries and in the shad gill nets.

OLLINS, J. W., and H. M. SMITH.

2. Report on the fisheries of the New England tates. Bull. U.S. Fish. Comm. 10:73-176.

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ITTEE ON NAMES OF FISHES.

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Acipenser brevirostrum is listed.

COMMITTEE ON RARE AND ENDANGERED WILDLIFE SPECIES.

1966. Rare and endangered fish and wildlife of the United States. U.S. Dep. Inter. Res. Publ. 34, var. pag.

Information for the shortnose sturgeon is presented on distinguishing characteristics, present distribution, former distribution, endangered status, estimated numbers, fecundity, reason for decline, protective measures already taken, measures proposed, number in captivity, and culture potential in captivity.

COPE, E. D.

1883. The fisheries of Pennsylvania. Rep. State Comm. Fish. 1881 and 1882:103-183.

Sturgeon are sold in the markets of Philadelphia and adjacent cities. Numerous fishing boats are engaged in taking them in strong nets, the catch is often very large.

CUERRIER, J. P.

1947. Quelques indications sur la taille de maturité la fréquence des pontes et la saison de ponte de l'Esturgeon de lac. Annals ACFAS 13, 100 p.

The article deals with *Acipenser* spawning season and size at maturity.

1951. The use of pectoral fin rays to determine age of sturgeon and other fish species. Can. Fish Cult. 11:10-18.

The aging method is applicable to shortnose sturgeon.

CURRIAN, H. W., and D. T. RIES.

1937. Fisheries investigation in the lower Hudson River IV. *In* A biological survey of the lower Hudson watershed, p. 125-145. Rep. N.Y. State Conserv. Dep., Suppl. 26 (11).

Ninety-five shortnose sturgeons ranging in length from 450 to 884 mm were examined. The diet of sturgeon in the lower Hudson included insects, crustaceans, mollusks, and annelids.

DADSWELL, M. J.

1975. The biology and resource potential of certain fishes in the St. Johns Estuary. (Mimeogr.) A report to the Department of Environment, Canada, from the Huntsman Marine Laboratory, 98 p.

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1976. Biology of the shortnose sturgeon (*Acipenser brevirostrum*) in the St. John River estuary, New Brunswick, Canada. Trans. Atl. Chap. Can. Soc. Environ. Biol. Annu. Meet. 1975:20-72.

Information on growth, length-weight relationships, food, fecundity, population estimates, and migrations.

DAHLBERG, M.

1975. Guide to coastal fishes of Georgia and nearby states. Univ. Georgia Press, Athens, 186 p.

A brief description and range of the shortnose sturgeon and a note that it is commonly caught in gill nets in the Altamaha River.

DEAN, B.

1894. Recent experiments in sturgeon hatching on the Delaware River. Bull. U.S. Fish Comm. 13:335-339.

Fish size is not mentioned, some shortnose sturgeon may have been used in the experiments.

1895. Fishes, living and fossil. An outline of their forms and probable relationships. Macmillan and Co., N.Y., 161 p.

A review of the internal and external anatomy of *Acipenser* is given. *Acipenser brevirostrum* is included in the classification.

DEES, L. T.

1961. Sturgeons. U.S. Fish Wildl. Serv., Fish. Leafl. 526, 8 p.

A review of the general life history and commercial value of sturgeons along with a brief description and more specific life history of each species, including the shortnose sturgeon.

DeKAY, J. E.

1842. Zoology of New York or the New York fauna. Part III. Reptiles and Amphibia. Albany, N.Y., 415 p.

The description given by LeSueur agrees with the Hudson River species. DeKay had seen it also in the markets of Norfolk, Va.

DIVISION OF LANDS AND FORESTS AND FISH AND GAME (New York).

1913. Third annual report of the conservation commission. J. B. Lyon Co., Albany, N.Y., 366 p.

Snails make up a large part of the food of the shortnose sturgeon in one of the ponds at the Linlithgo Hatchery.

DUMÊRIL, A.

1867. Prodrome d'une monographie des
geons et description des espèces de l'Améri
Nord qui appartienment au sous genre
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188.

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Lophobranches. Librairie Encyclopédique
Roret, Paris, p. 170-173.

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EDDY, S.

1957. How to know the freshwater fishes.
Brown Co., Dubuque, Iowa, 286 p.

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EVERMANN, B. W., and B. A. BEAN.

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Comm. Fish. 1897:227-248.

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EVERMANN, B. W., and W. C. KENDALL.

1900. Check-list of the fishes of Florida
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(Jordan 1884), and Indian River as *Aciper*
brevirostris (Evermann and Bean 1896)

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Fish. 1901:217-225.

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St. Lawrence is erroneously cited in
references: in the St. Lawrence and
flowing into it (Fortin 1864) and in
Lawrence and lacs St. Pierre, St. Louis, and
Froid (Montpetit 1897).

FEGELY, T.

1977. Taking a closer look: Pennsylvania's
gered cold-blooded animals. Pa.
46(12):4-5.

The shortnose sturgeon is on both state and federal endangered lists. A picture is included.

IN, P.
1864. Continuation of the list of fish of the Gulf and River St. Lawrence. Annu. Rep. Fish. Append., p. 60-72.

The first occurrence of the shortnose sturgeon in the St. Lawrence River is recorded. Vladykov and Greeley (1963) report that this record is *A. fulvescens*.

ER, H. W.
1905. The fishes of New Jersey. Rep. N.J. Mus., 477 p.

Fowler to date had not collected it from New Jersey. He reports a record from shallow water at the island by Trenton in the Delaware.

1910. Notes on chimaeroid and ganoid fishes. Proc. Acad. Nat. Sci. Phila. 62:603-612.

The article gives a list of the species collected with descriptions and location where found. Three examples of *A. brevirostrum* were examined.

1912. Records of fishes from the middle Atlantic states and Virginia. Proc. Acad. Nat. Sci. Phila. 64:34-59.

The shortnose sturgeon is reported at Torresdale, Philadelphia County. The author also found one at Bristol, Bucks County, in May 1908.

19. Notes on New Jersey, Pennsylvania, and Virginia fishes. Proc. Acad. Nat. Sci. Phila. 17:292-300.

The shortnose sturgeon is included.

1920. A list of the fishes of New Jersey. Proc. Biol. Soc. Wash. 33:139-170.

The shortnose sturgeon is listed as occurring at Burlington, Cape May, Mercer, and Gloucester counties.

45. A study of the fishes of the Southern Piedmont and coastal plain. Wickersham Printing Co., Phila., 408 p.

The shortnose sturgeon is known in the Potomac, Neuse, and St. John's Rivers.

52. A list of fishes of New Jersey, with off-shore species. Proc. Acad. Nat. Sci. Phila. 104:89-151.

The shortnose sturgeon is listed with its range.

FRIED, S. M., and J. D. McCLEAVE.
1973. Occurrence of the shortnose sturgeon (*Acipenser brevirostrum*), an endangered species, in Montsweag Bay, Maine. J. Fish. Res. Board Can. 30:563-564.

Thirty-one shortnose sturgeons were caught in the summers of 1971 and 1972. Of nine fish preserved for study, six were stated to be longer than any previously documented and four exceeded the maximum total length previously postulated, but they overlooked Gorham's (1971) report of a 1,295-mm specimen. These specimens represent the second population of this species found in the Gulf of Maine.

GEOLOGICAL SURVEY OF NEW JERSEY.
1890. Final report of the state geologist. Vol. II. Mineralogy. Botany. Zoology. The John L. Murphy Publishing Co., Trenton, N.J., p. 668-669.

The shortnose sturgeon is found in the Delaware in proportion to the common sturgeon at about 5 to 1.

GILL, T.
1862. Catalogue of the fishes of the eastern coast of North America from Greenland to Georgia. Proc. Acad. Nat. Sci. Phila. 13(Suppl.):1-63.

Acipenser brevirostrum is included.

1873. Catalogue of the fishes of the east coast of North America. Rep. U.S. Comm. Fish. 1871-1872:779-814.

The shortnose sturgeon is listed with its range.

GOODE, G. B.
1879. Catalog of the collections to illustrate the animal resources and the fisheries of the United States. Bull. U.S. Natl. Mus. 14, 64 p.

Acipenser brevirostrum is included in a list of animals of North America which are beneficial or injurious to man.

GOODE, G. B., and T. H. BEAN.
1879. A list of the fishes of Essex County including those of Massachusetts Bay. Bull. Essex Inst. 11, 351 p.

The species is represented in the museum of the Essex Institute by a stuffed skin obtained at Rockport.

GOODE, G. B., and a Staff of Associates.

1884. The fisheries and fishery industries of the United States. Sec. I. Natural history of useful aquatic animals. Gov. Print. Off., Wash., D.C., 895 p.

The shortnose sturgeon is described along with a brief natural history. The sturgeon's ability to leap out of the water is mentioned. Plate 243 is from a drawing from a photograph of a specimen of shortnose sturgeon collected from Woods Hole, Mass., 1871.

1887. The fisheries and fishery industries of the United States. Sec. V. History and methods of the fisheries. Gov. Print. Off., Wash., D.C., 881 p.

Sturgeon are included in a review of the river fisheries of the Atlantic States. Size and species were not mentioned and the shortnose sturgeon is probably included.

GORDON, B. L.

1960. The marine fishes of Rhode Island. The Bait and Tackle Shop, Watch Hill, R.I., 136 p.

A 2.5-ft shortnose sturgeon was taken in May 1956 in the traps at Point Judith. A 28-in fish believed to be a shortnose sturgeon was taken in Narragansett Bay in 1957.

GORHAM, S. W.

1965a. Distributional checklist of the fishes of New Brunswick. New Brunswick Museum, Canada, p. 1-32.

The shortnose sturgeon is included with a locality record.

1965b. Notes on the fishes from the Browns Flat area, Kings County, New Brunswick. Can. Field-Nat. 79:137-142.

Eight specimens were collected using salmon nets.

1971. The shortnose sturgeon, *Acipenser brevirostrum*, an endangered species in New Brunswick? Mus. Mem. N.B. Mus. 3:13-15.

The article presents new records of specimens in the St. John system and data on length and weight. The longest specimen is recorded to this date.

GORHAM, S. W., and D. E. McALLISTER.

1974. The shortnose sturgeon, *Acipenser brevirostrum*, in the Saint John River, New Brunswick, Canada, a rare and possibly endangered species. Natl. Mus. Nat. Sci., Syl. 5:5-16.

The paper provides new information for a series of specimens from the St. John system on distribution, length, and weights. A taxonon
scription of the Canadian population is gi
the first time. Pictures are included. A new maximum size, greater than that reported by Gorham (1971), is reported.

GREELEY, J. R.

1937. Fishes of the area with annotated list.
biological survey of the lower Hudson watershed
p. 45-103. Rep. N.Y. State Conserv. Dep., Suppl
26(11).

The article includes information on length
weight relationships, spawning times, growth
and distribution in the Hudson River es

GRUNCHY, C. G., B. PARKER, and D. E. McALLISTER.

In press. Shortnose sturgeon. *In* D. S. Lee
Carter, D. E. McAllister, J. R. Stauffer,
Hocutt, R. E. Jenkins, and J. McCann, Atlas o
North American freshwater fishes. J. N.C.
Mus.

A spot distribution map, illustration, an
species account of shortnose sturgeon is

GRZIMEK'S ANIMAL LIFE ENCYCLOPEDIA.

1973. Polypterids, sturgeons and relate
forms. Van Nostrand Reinhold Co., N.Y.,
531 p.

A very brief description of *A. brevirostrum* wit
a comment on its commercial value.

GÜNTHER, A.

1870. Catalogue of the fishes of the
Museum. Taylor and Francis, Lond., Vol. 8

A taxonomic description is given.

HALKETT, A.

1913. Checklist of the fishes of the Dominion o
Canada and Newfoundland. King's Printer, Ottowa, 138 p.

Acipenser brevirostrum is contained in the list
with its general range of distribution including
the erroneous St. Lawrence record.

HARKNESS, W. J. K.

1923. The rate of growth and the food of th
sturgeon (*Acipenser rubicundus* (LeSu
Publ. Ont. Fish. Res. Lab. 18:13-42.

The author found the earstones or otoliths
sturgeon to form growth lines. Technique

lered to be 20,000 t (30,000 t allocated), and the U.S. cial catch 3,000 t (6,000 t allocated). The catch tries without specific allocations ("Others") hich were expected to take some Atlantic mackerel as -catch was chosen as 100 t (5,100 t allocated) because of severe catch restrictions for many other species. The U.S. recreational catch was arbitrarily considered to be the same in 1977 as in 1976 (5,000 t). The total catch in 1977 was, therefore, taken to be 92,000 t for the purpose of this assessment.

Table 8.—Atlantic mackerel catch (commercial and recreational) (millions of fish) from ICNAF Subareas 3, 4, and 5 and Statistical Area 6 during 1962-77.

Year class	Year															
	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
1951	0.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1952	0.2	0.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1953	0.6	0.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1954	1.1	0.2	0.3	—	—	—	—	—	—	—	—	—	—	—	—	—
1955	2.1	0.2	1.0	—	—	—	—	—	—	—	—	—	—	—	—	—
1956	2.3	0.2	0.8	0.9	—	—	—	—	—	—	—	—	—	—	—	—
1957	1.7	0.4	4.8	4.8	0.2	—	—	—	—	—	—	—	—	—	—	—
1958	5.5	8.1	5.1	5.1	0.6	0.4	0.1	—	—	—	—	—	—	—	—	—
1959	22.1	35.2	24.0	23.6	26.4	39.8	7.6	9.5	3.0	—	—	—	—	—	—	—
1960	4.0	1.7	4.9	6.3	9.6	7.5	1.2	2.5	4.0	7.5	—	—	—	—	—	—
1961	23.3	5.6	5.1	4.9	5.7	6.3	0.8	3.5	10.6	8.4	5.7	—	—	—	—	—
1962	—	1.5	8.6	3.5	3.2	4.1	8.2	2.3	10.5	4.4	3.8	1.6	—	—	—	—
1963	—	—	15.9	4.3	6.4	4.3	17.8	3.4	5.6	3.7	8.3	3.8	0.8	—	—	—
1964	—	—	—	10.9	13.9	24.4	47.3	6.5	7.5	9.2	4.3	4.1	2.5	1.0	—	—
1965	—	—	—	—	29.0	33.0	73.6	75.0	29.4	35.8	24.4	10.9	6.4	2.3	1.4	—
1966	—	—	—	—	—	1.0	76.3	183.2	173.5	210.8	88.6	31.1	25.7	12.5	13.2	0.5
1967	—	—	—	—	—	2.2	175.5	298.8	556.0	579.0	396.2	196.7	108.3	50.7	22.4	3.8
1968	—	—	—	—	—	—	1.4	8.1	58.1	132.0	185.3	191.9	111.8	52.1	34.2	4.9
1969	—	—	—	—	—	—	—	4.5	206.1	304.8	260.0	232.9	114.3	68.1	40.0	8.1
1970	—	—	—	—	—	—	—	—	5.1	77.3	87.0	284.2	101.5	58.9	27.0	8.0
1971	—	—	—	—	—	—	—	—	—	2.5	22.4	282.3	264.4	101.3	51.8	12.2
1972	—	—	—	—	—	—	—	—	—	—	3.6	161.4	242.2	114.2	84.7	13.7
1973	—	—	—	—	—	—	—	—	—	—	—	4.0	95.9	433.3	269.4	71.0
1974	—	—	—	—	—	—	—	—	—	—	—	—	2.0	375.4	349.5	130.5
1975	—	—	—	—	—	—	—	—	—	—	—	—	—	3.7	12.3	33.0
1976	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2.1
Total	63.3	53.5	70.5	64.3	95.0	123.0	409.8	597.3	1,069.4	1,375.4	1,089.6	1,404.9	1,075.8	1,273.5	905.9	287.8
Obs. wt.[1]	16.6	17.3	21.7	24.7	32.4	47.6	109.9	165.1	262.7	403.7	431.6	429.2	347.2	293.7	243.0	92.0
Calc. wt.[1,2]	15.3	18.2	23.1	25.5	30.7	48.0	84.4	144.7	276.8	429.2	396.2	435.3	346.9	308.7	268.1	93.3
Obs./calc. wt.	1.085	0.951	0.939	0.969	1.055	0.992	1.302	1.141	0.949	0.941	1.089	0.986	1.001	0.951	0.906	0.986
Mean age	2.8	3.9	3.8	4.7	3.9	4.8	2.3	2.8	3.0	3.6	4.2	3.6	3.8	2.8	3.5	3.8

[1] Thousands of tons.

[2] Using mean weights at age from Table 1.

Catch Composition

Table 8 contains estimates of the Atlantic mackerel catch in numbers at age during 1962-77. Ages ranged between 0 and 10+. Average age of the catch during the period was 3.6 yr, with annual mean ages ranging between 2.3 and 4.8 yr. In 1977, 45% of the catch in numbers was age 3 fish, with a mean age of 3.8 yr. Predominant age groups in the catches have varied, generally reflecting the passage of dominant year classes through the fishery.

Abundance Indices

United States research vessel bottom trawl survey catch-per-tow data (Table 9) indicate a continued decline in Atlantic mackerel abundance. The spring survey catch-per-tow (kilograms) index decreased 37% from 1976 to 1977. Both the spring and autumn indices have demonstrated a continuous biomass decline since 1968-69 (Fig. 3). The spring survey mean catch per tow in numbers has also declined continuously (Table 10) and has shown a marked decrease in the number of age 1 Atlantic mackerel in 1976 and 1977.

The standardized U.S. commercial catch-per-day index (Table 11) has generally been consistent with estimates of abundance from survey data and with stock biomass estimates obtained from cohort analysis (Table 12), although it increased in 1975 and 1976 whil the other indices continued to decrease. The U.S. co cial index may be limited as a measure of overall stock abundance because it has been based on small inshore catches, and particularly since these catches have prised an increasingly smaller proportion of the catch in recent years. The U.S. Atlantic mackerel catch from directed effort averaged 3.6% of the international catch each year during 1964-67, 1.4% in 1968-69, during 1970-76, and <0.1% in 1974-75. The increa the index in 1975-76 may reflect only localized improvements in abundance.

Distant-water fleet catch-per-effort data are sidered to be unreliable as a measure of Atlantic erel abundance. Previous analysis of distant-water fleet statistics by Anderson (1976) indicated that various country-vessel tonnage classes experienced differen terns of catch per hour fished during 1968-74, m which were not in agreement with the change in stock biomass determined by cohort analysis. Total stoc mass peaked in 1969 (Table 12) and then declined s ly, whereas distant-water fleet catch per effort generally increased or was erratic in year-to-year changes. Anderson (1976) suggested that learning, improver in vessel efficiency through technological chang both occurred in varying degrees for nearly all country-tonnage classes engaged in the Atlantic mackerel fishery which invalidates their catch rates as consi measures of stock abundance. In view of the pre inconsistency in these data, it is difficult to interpret the current catch rates. Although 1977 data are not available, 1976 data indicated increases in catch per effo certain Bulgarian, German Democratic Republic, Polish vessel classes and decreases for some U.S.S.R. vessels. The difficulty in interpreting distant-water catch rates was recognized at the time of the last IC assessment (ICNAF 1977), and it was also felt that a schooling species such as Atlantic mackerel was subject to continued accessibility to fishing gear even a levels of abundance.

Table 9.—Stratified mean catch (kilograms) per tow (ln and retransformed) of Atlantic mackerel from United States bottom trawl surveys in the spring (strata 1-25, 61-76) and autumn (strata 1-2, 5-6, 9-10, 13, 16, 19-21, 23, 25-26).

	Spring[1]		Autumn[2]	
Year	ln	Retransformed	ln	Retransformed
1963	—	—	.013	.016
1964	—	—	<.001	<.001
1965	—	—	.046	.073
1966	—	—	.057	.085
1967	—	—	.195	.372
1968	.575	3.998	.117	.217
1969	.029	0.065	.154	.459
1970	.471	2.039	.068	.099
1971	.425	1.969	.052	.073
1972	.354	1.332	.070	.107
1973	.228	0.748	.034	.043
1974	.277	0.769	.046	.108
1975	.121	0.255	.010	.016
1976	.144	0.317	.028	.039
1977	.118	0.199	—	—

[1]Based on catches with No. 41 trawl; 1968-72 catches were with No. 36 trawl and were adjusted to equivalent No. 41 catches using a 3.25:1 ratio (41/36).

[2]Based on catches with No. 36 trawl.

Table 11.—Atlantic mackerel catch per standardized U.S. day fished.

Year	Catch per day (metric tons)	Year	Catch per day (metric tons)
1964	0.43	1971	1.29
1965	0.49	1972	0.84
1966	0.84	1973	0.53
1967	1.75	1974	0.17
1968	2.80	1975	0.53
1969	1.92	1976	0.59
1970	2.07		

Table 10.—Stratified mean catch (number) per tow of Atlantic mackerel by year class from the 1973-76 U.S. spring bottom trawl surveys in ICNAF Subarea 5 and Statistical Area 6, strata 1-25, 61-76.

	Year class														
Year	1976	1975	1974	1973	1972	1971	1970	1969	1968	1967	1966	1965	1964	1963+	Total
1973	—	—	—	—	1.949	6.683	8.188	15.957	3.669	21.081	6.309	3.319	0.365	0.574	68.094
1974	—	—	—	2.067	0.749	1.347	0.185	0.492	0.249	1.401	0.440	0.237	0.107	—	7.274
1975	—	—	5.330	1.101	0.141	0.128	0.030	0.028	0.020	0.014	0.001	—	—	—	6.793
1976	—	0.447	4.928	0.365	0.070	0.014	0.006	0.009	—	0.004	—	—	—	—	5.843
1977	0.043	0.254	0.340	0.153	0.050	0.017	0.010	0.024	0.011	0.018	0.007	0.019	—	—	0.946

Table 12.—Atlantic mackerel stock size by age in ICNAF Subareas 3, 4, and 5 and Statistical Area 6 (millions of fish) derived from cohort analysis assuming natural mortality (M) = 0.30 and fishing mortality (F) = 0.39 at ages 4 and older in 1977. Values in parentheses estimated.

Year class	Year 1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
1951	12.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1952	7.8	5.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1953	8.3	5.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1954	18.1	12.5	9.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1955	57.8	41.0	30.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1956	55.2	38.9	28.6	20.5	—	—	—	—	—	—	—	—	—	—	—	—	—
1957	39.7	27.9	20.3	10.9	4.0	—	—	—	—	—	—	—	—	—	—	—	—
1958	53.7	35.1	19.0	9.7	2.8	1.5	0.8	—	—	—	—	—	—	—	—	—	—
1959	877.3	630.9	437.1	303.2	204.3	128.6	61.0	38.7	20.5	—	—	—	—	—	—	—	—
1960	741.0	545.5	402.6	294.1	212.4	149.1	104.0	76.0	54.2	36.7	—	—	—	—	—	—	—
1961	920.5	661.9	485.5	355.3	259.0	187.0	133.1	97.9	69.5	42.4	24.2	—	—	—	—	—	—
1962	—	429.5	316.9	227.3	165.4	119.8	85.2	56.1	39.6	20.3	11.2	5.0	—	—	—	—	—
1963	—	—	429.5	304.5	221.9	158.9	114.0	69.1	48.3	30.9	19.7	7.5	2.3	—	—	—	—
1964	—	—	—	542.2	392.3	278.7	185.4	96.7	66.0	42.4	23.5	13.7	6.6	2.8	—	—	—
1965	—	—	—	—	1,212.9	873.6	618.8	395.0	228.1	143.7	75.6	35.0	16.6	6.8	3.0	—	—
1966	—	—	—	—	—	3,165.3	2,344.1	1,670.8	1,080.1	650.8	300.7	146.5	81.8	38.5	17.7	1.8	0.9
1967	—	—	—	—	—	—	7,786.5	5,617.3	3,904.2	2,413.8	1,289.8	614.5	285.9	118.6	44.2	13.5	6.8
1968	—	—	—	—	—	—	—	3,114.3	2,300.1	1,654.0	1,111.7	664.1	326.8	145.9	63.2	17.4	8.7
1969	—	—	—	—	—	—	—	—	3,244.9	2,226.5	1,387.1	803.8	395.0	194.2	85.3	28.8	14.4
1970	—	—	—	—	—	—	—	—	—	1,657.5	1,161.4	785.5	337.3	162.5	69.7	28.4	14.2
1971	—	—	—	—	—	—	—	—	—	—	1,711.9	1,248.9	682.2	277.8	118.6	43.3	21.7
1972	—	—	—	—	—	—	—	—	—	—	—	1,212.6	759.4	354.1	164.1	48.6	24.4
1973	—	—	—	—	—	—	—	—	—	—	—	—	1,981.2	1,385.1	653.2	252.0	126.4
1974	—	—	—	—	—	—	—	—	—	—	—	—	—	(2,360.0)	1,428.6	760.9	452.4
1975	—	—	—	—	—	—	—	—	—	—	—	—	—	—	(810.0)	589.4	408.3
1976	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	(415.0)	305.6
1977	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	(415.0)
Stock size (age 1+)																	
Total (10^6)	2,791.8	2,434.4	2,178.8	2,067.7	2,675.0	5,062.5	11,432.9	11,231.9	11,055.5	8,919.0	7,116.8	5,537.1	4,875.1	5,046.3	3,457.6	2,199.1	1,798.8
Wt (10^3 tons)[1]	626.7	584.9	582.2	577.3	674.9	886.7	2,150.3	2,404.2	2,285.6	2,161.3	2,099.5	1,522.1	1,186.5	964.1	702.2	524.4	468.6
Spawning stock (50% age 2, 100% age 3+)																	
Total (10^6)	1,500.8	1,674.0	1,590.9	1,373.3	1,266.0	1,460.0	2,474.4	5,309.0	6,660.6	6,148.3	4,824.2	3,700.1	2,514.2	1,993.8	1,933.3	1,489.4	1,231.0
Wt (10^3 tons)[1]	461.4	491.0	517.8	501.6	517.1	512.6	920.2	1,505.8	1,802.1	1,829.9	1,811.7	1,300.8	931.6	635.6	519.3	434.7	402.5

[1] Adjusted using ratio of observed to calculated weights in Table 8.

g Mortality

Instantaneous fishing mortality (F) for ages 4 and 1977 was estimated to be 0.39 (see section on ethods). Age-specific F values computed from cohort analysis, assuming instantaneous natural mortality (M) = 0.30, for 1962-76 are given in Table 3. Mean annual F values for ages 3 and older were stable during 1962-64, averaging 0.04, and then increased steadily to a peak of 0.74 in 1976.

Recruitment

The estimated sizes of the 1961-73 year classes at age 1, computed by cohort analysis, are given in Table 12 and plotted in Figure 9. Sizes ranged between 430 million fish (1962 and 1963 year classes) and 7,786 million fish (1967 year class) and averaged 2,108 million. Only 4 of these 13 year classes were above the mean. The median size was 1,658 million.

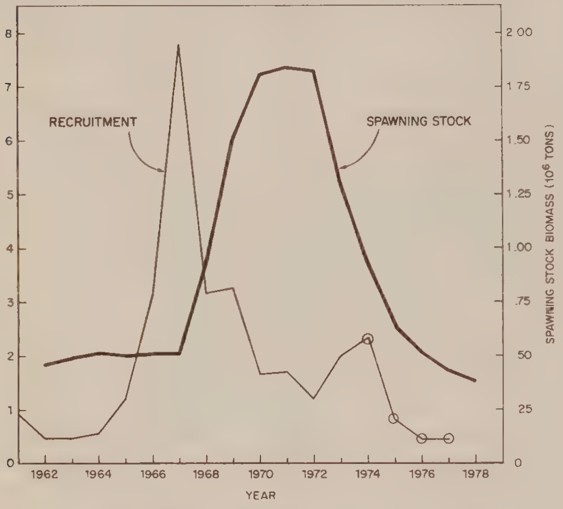

Figure 9.—Atlantic mackerel spawning stock biomass (metric tons) in 1962-77 and abundance at age 1 of the 1961-77 year classes from cohort analysis. Open circles indicate estimated year-class sizes.

The 1974 year class at age 1 was estimated to be 2,516 million fish based on the autumn survey age 0 index (Table 4, Fig. 6) and 2,104 million based on the spring survey age 1 index (Table 5, Fig. 7). At age 2 this year class was estimated to be 1,488 million fish based on the spring survey age 2 index (Table 5, Fig. 8). The corresponding catch of 349.5 million fish at age 2 in 1976 (Table 8) implies, using Equation (3), an *F* of 0.314. It then follows that the size of this year class at age 1 (from cohort analysis) would be 2,447 million fish. The mean of the above three estimates at age 1 was 2,356 million fish. The catch of 375.4 million fish at age 1 in 1975 (Table 8) and the year-class estimates of 2,516 and 2,104 million fish at age 1 result, using Equations (2) and (3), in year-class estimates at age 2 of 1,543 and 1,238 million fish, respectively. The mean of these two estimates and the other estimate of 1,488 million at age 2 was 1,423 million fish. The reported catch of 349.5 million at age 2 from a year-class size of 1,423 million fish requires, from Equation (3), an *F* of 0.331. Cohort analysis, using this *F* at age 2 in 1976, results in a year-class size of 2,358 million fish at age 1 in 1975. Given this estimate and the mean (2,356 million) of the three other estimates, the 1974 year class at age 1 was set at 2,360 million fish.

The 1975 year class at age 1 was estimated to be 614 million fish based on the autumn survey age 0 index (Table 4, Fig. 6) and 915 million based on the spring survey age 1 index (Table 5, Fig. 7). At age 2 this year clas was estimated to be 652 million fish based on the survey age 2 index (Table 5, Fig. 8). The catch million fish at age 2 in 1977 (Table 8) implies, fro Equation (3), an *F* of 0.060, which then infers (fro cohort analysis) a year-class size of 898 million fish 1 in 1976. The mean of the above three estimates was 809 million fish. The catch of 12.3 million fish at ag 1 in 1976 (Table 8) and the year-class estimates of 61 and 915 million fish at age 1 result, from Equati and (3), in year-class estimates at age 2 of 444 a million fish, respectively. The mean of these two esti mates and the other estimate of 652 million at age 2 wa 588 million fish. The reported catch of 12.3 million age 2 from a year-class size of 588 million fish requ *F* of 0.067. Cohort analysis, using this *F* at age 2 in 1977 results in a year-class size of 809 million fish at a 1976. Given this estimate and the mean (809 mil the three other estimates, the estimated size of th 197 year class at age 1 was considered to be 810 million fish.

The 1976 year class at age 1 was estimated to million fish based on the spring survey age 1 index 5, Fig. 7). There were no fish from this year class caugh at age 0 (Table 4) during the 1976 autumn survey. Th survey catch-per-tow index for this year class a ages 0 and 1 was lower than for any other year cla ing 1963-77 (Tables 4, 5). This indicates that this yea class may be very weak. Previously the weakest yea classes since 1961 appeared in 1962 and 1963 (430 fish at age 1). Based on the single estimate from th spring survey data, the size of the 1976 year class at age was set at 415 million fish.

There are no estimates of the size of the 1977 yea available. Since the contribution of age 1 fish to th 197 catch is expected to be low, estimation of the size of th 1977 year class is not particularly critical to the res the assessment. However, the consequences of ov mating the size of this year class are more detrimental t conservation management than of underestimating it. I the year class is underestimated, any unrealized c at age 1 can be regained in later years since yield cruit reaches a maximum at about age 4 (ICNAF 1973). However, if the year class is overestimated, the 1978 allowable catch may be set too high to achieve m ment objectives and the 1979 stock size would b less than projected. The 1977 year class at age 1 was, therefore, set at the minimum level of the weak 197 class.

Partial Recruitment

Atlantic mackerel appear to have been fully rec to the fishery at age 3 and older in recent years, based on age-specific mortality rates (Table 3). Partial recruitment at ages 1 and 2 varied considerably during 1 (Table 13). Partial recruitment at age 1 ranged fro 100% and at age 2 from 16 to 90%. Values prior to 1968 are less precise than those since because the numb age data for 1962-67 are based on very limited sa data and are not as reliable as later data (Anderso able 13.—Percentage of fishing mortality (F) of Atlantic mackerel at ages 1 and 2 compared with mean at ages 3 and older (partial recruitment).

ear	Age 1	Age 2	Year	Age 1	Age 2
962	78.9	15.8	1970	41.6	16.2
1963	9.5	23.8	1971	20.9	64.6
1964	100.0	82.1	1972	4.7	28.8
965	46.2	32.7	1973	37.3	67.6
966	46.7	70.0	1974	11.3	89.9
1967	0.9	40.5	1975	38.0	85.0
1968	17.4	25.2	1976	2.4	44.3
969	2.1	44.4	1977	1.5	17.2

e footnote 2). Partial recruitment at ages 1 (1.5%) and 2 7.2%) in 1977 was near the low end of the range of In view of the wide fluctuations evident in previ- s, the 1977 partial recruitment coefficients may t reflect the situation that would actually occur in 78. An average of the 1968-77 values (except 1970, d 1975) was used for age 1 in 1978 (9%). The high n 1970 and 1975 were excluded from this average cause they occurred as a result of large catches taken ong incoming year classes which does not repre- expected situation in 1978. The high 1973 value as also excluded because it resulted from a large rvest of age 1 fish from a year class of below-averge is catch reflected a shifting of intensive fishing to younger age groups in an attempt to maintain gh levels of catch at a time when older age groups exbited a sharp drop in abundance.

erage of the 1968-77 values (except 1974-75) was age 2 in 1978 (39%). The 1974-75 values were exuded because they were unusually high and do not present the expected situation for 1978. Such high may have resulted from: 1) large catches being om strong year classes, and 2) apparent diversion fishing effort onto that age group from older age groups tempt to maintain high levels of catch. Partial re- nt in 1978 was, therefore, predicted to be 9% at e 1, 39% at age 2, and 100% at ages 3 and older (Table).

14.—Summary of parameters used in the Atlantic mackerel assessment.

Parameter		Value
ng mortality in 1977 (age 4+)		0.39
itment at age 1:	1974 year class	$2{,}360.0\times10^6$
	1975 year class	810.0×10^6
	1976 year class	415.0×10^6
	1977 year class	415.0×10^6
l recruitment in 1978 (%):	age 1	9
	age 2	39
	age 3+	100
1978 spawning stock (10^3 tons) projection		402.5

Size

Age-specific stock size estimates generated from analysis and summed biomass values determined lying mean weights at age to these estimates are ven in Table 12. Total stock biomass (age 1 and older) creased from about 600,000 t in 1962-66 to a peak of 2.4 t in 1969 and then declined steadily to an esti- 524,400 t in 1977. Spawning stock biomass, consisting of 50% of the age 2 fish and 100% of the age 3 and older fish (Isakov[13]; Moores [14]), increased from around 500,000 t during 1962-67 to 1.8 million t in 1970-72 before decreasing to 434,700 t in 1977 (Fig. 9).

Catch and Stock Size Projections

Under the assumption that the 1977 catch would be 92,000 t, the total stock biomass at the beginning of 1978 was estimated to be 468,600 t (11% decrease from 1977) with a spawning stock biomass of 402,500 t (7% decrease from 1977). Catch options for 1978 and resultant spawning stock biomass levels in 1979 were calculated for values of F ranging from 0 to 0.70 (Table 15). In the absence of any catch in 1978 ($F = 0.00$), the spawning stock biomass would increase about 6% from 1978 to 428,000 t in 1979. A catch of 23,500 t ($F = 0.07$) would maintain the spawning stock in 1979 at the 1978 level.

Table 15.—Projected Atlantic mackerel catch (metric tons) in ICNAF Subareas 3, 4, and 5 and Statistical Area 6 in 1978 with fishing mortality ranging from 0.00 to 0.70, and the resulting spawning stock in 1979 and its percentage change from 1978.

Fishing mortality (F)	Total mortality (Z)	Catch in 1978 (10^3 tons)	Spawning stock in 1979 (10^3 tons)	% change in spawning stock from 1978 (by weight)
0.00	0.30	0.0	428.0	+6.3
0.05	0.35	16.9	409.6	+1.8
0.07	0.37	23.5	402.5	0.0
0.10	0.40	33.0	392.6	−2.5
0.15	0.45	48.5	376.3	−6.5
0.20	0.50	63.2	360.8	−10.4
0.25	0.55	77.3	346.0	−14.0
0.30	0.60	90.8	331.9	−17.5
0.35	0.65	103.7	318.5	−20.9
0.40	0.70	116.0	305.6	−24.1
0.45	0.75	127.8	293.4	−27.1
0.50	0.80	139.0	281.7	−30.0
0.55	0.85	149.8	270.6	−32.8
0.60	0.90	160.1	260.0	−35.4
0.65	0.95	170.0	249.8	−37.9
0.70	1.00	179.5	240.1	−40.3

Equilibrium yield calculations, assuming a constant level of recruitment at age 1 and partial recruitment of 9, 39, and 100% at ages 1, 2, and 3+, respectively, indicate that $F_{0.1} = 0.40$. The $F_{0.1}$ level, defined as the level of F at which the change in yield per recruit with respect to the change in F is only 10% of that which would occur if the fishery began on the virgin stock (Gulland and Boerema 1973), has been used recently within ICNAF as a basis for setting catch quotas. Fishing mortality at $F_{0.1} = 0.40$ would result in a 1978 catch of 116,000 t and would reduce the spawning stock by 24% in 1979.

An assessment assuming a total catch of 110,000 t in 1977 (TAC of 105,000 plus 5,000 for the U.S. recreational catch) instead of 92,000 t has no significant effect on the catch projections for 1978. The fishing mortality estimate for 1977 would be 0.435 instead of 0.39 and the projected spawning stock biomass in 1978 would be about 390,000 t instead of 402,500 t. A catch of about 25,000 t, instead of 23,500 t, could be taken in 1978 and still maintain the spawning stock in 1979 at the 1978 level.

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DISCUSSION

The accuracy of the projected catch options for 1978 and the resultant spawning stock biomass levels in 1979 (Table 15) is dependent upon the accuracy of the data and parameters used in the analysis. The variability and bias associated with these data and parameters are evident.

The U.S. recreational catches (Table 6) are estimated and lack any measure of accuracy or reliability, and the validity of the international commercial statistics is uncertain. The numbers at age in the catch (Table 8) were generated from length and age samples contributed by various countries, and although ICNAF established recommended sampling procedures, the validity of the samples is unknown. Anderson et al. (see footnote 11) found significant differences in age interpretation and age-length keys between countries during 1970-76, particularly in 1976. As indicated earlier, country age-length keys for 1976 were combined in an attempt to modulate these differences. The procedure recommended by ICNAF specifies stratified age samples, whereas Kimura (1977) showed that random age samples are more accurate.

The U.S. bottom trawl survey data provided the basis for estimating the size of the recruiting year classes (Tables 4 and 5, Figs. 6-8) and also for predicting fishing mortality in 1977 (Table 2, Fig. 5). Although confidence limits were not given for any of these estimates, survey catch-per-tow data in general are subject to high variability (Grosslein 1971), and particularly so for Atlantic mackerel (Anderson 1976; Sissenwine 1978) since it is a pelagic schooling species. Therefore, even though the relationships using survey catch-per-tow data to predict year-class sizes and fishing mortality are statistically significant, the predicted values are necessarily somewhat imprecise.

The values for instantaneous natural mortality (M = 0.30) and partial recruitment coefficients, although having a basis for being chosen, introduce additional uncertainty to the final results.

In view of all the variability and uncertainty in the data, the results of this assessment must be treated with appropriate caution. Given the catch and stock size projections, fishery managers may set allowable catch levels for 1978 appropriate to management objectives which they have adopted. Since highly precise projections are currently not available, the decision process should include consideration of the acceptable level of risk of failing to achieve management objectives. If an objective is to rebuild the stock by a certain percentage from 1978 to 1979, it may be wise to set the catch in 1978 at a level corresponding to a greater percentage increase in stock size as a safety factor to guard against the probability that the predicted stock size and recruitment levels are, in fact, overestimated. According to the ery Conservation and Management Act of 1976 e by Congress, the level of catch must consider relevant economic, social, or ecological factors. Since economic and social factors are beyond the scope of this pape ecological or biological considerations will be disc sed.

The historical relationship between Atlantic mackerel spawning stock and recruitment is shown in Fig The spawning biomass estimated for 1978 is s below the 1962-67 level when, prior to the recent decade of intensive international fishing, catches averaged only about 25,000 t and stock size was relatively stabl spawning biomass of about 500,000 t present in 1 produced year classes ranging from the weakest (1962-63) to the strongest (1967). The large spawning stocks present during the late 1960's-early 1970's produced above- and below-average year classes. It appear for Atlantic mackerel, as for most species, spawning stock size alone exerts little influence on the size of a year class unless perhaps the spawning stock is reduced tremely low levels. Lett and Kohler[15] found in population simulations of Atlantic herring, *Clupea harengus*, in the Gulf of St. Lawrence that recruitment was ind dent of spawning stock size over a fairly wide rang that a stock-recruitment relationship emerged only when the stock was collapsing due to overfishing. Environmental factors are obviously a major influence on tic mackerel year-class size, but the present st knowledge concerning this influence is inadequate for assessment use. Consequently, it is virtually impossible to define an optimum or minimum spawning sto at or above which level adequate recruitment c predicted or below which weak recruitment is likely. However, since spawning stock size has contin steady decline and recent year classes (1975-76) a to be as weak as any observed previously, there is reason for concluding that the spawning stock should not be allowed to fall much below the projected 1978 leve

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Assessment of the Northwest Atlantic Mackerel, *Scomber scombrus*, Stock

Emory D. Anderson

April 1979

U.S. DEPARTMENT OF COMMERCE
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Assessment of the Northwest Atlantic Mackerel, *Scomber scombrus*, Stock

EMORY D. ANDERSON[1]

ABSTRACT

The status of the Atlantic mackerel, *Scomber scombrus*, stock in the International Commission for the Northwest Atlantic Fisheries (ICNAF) convention area is analyzed in this paper. Total catch declined from a high of 431,606 t in 1972 to an estimated 92,000 t in 1977. The U.S. spring bottom trawl survey has shown a continuous decrease in Atlantic mackerel abundance since 1968. Fishing mortality (*F*) in 1977 was estimated at 0.39, nearly one-half of the 1976 level and the lowest since 1972. The 1974 year class appears to be the strongest since 1969, whereas the 1975 and 1976 year classes appear to be very weak. Spawning stock biomass decreased from 1.8 million t in 1970-72 to an estimated 402,500 t at the beginning of 1978, which is slightly below the 1962-67 level when catches averaged only about 25,000 t. A zero catch in 1978 would increase the 1979 spawning stock by 6%; a catch of 23,500 t (F = 0.07) would maintain the spawning stock at the 1978 level.

INTRODUCTION

The following report analyzes the status of the Northwest Atlantic mackerel, *Scomber scombrus*, stock biting the waters from Cape Hatteras, N.C., to New- dland, which is the area included in ICNAF (International Commission for the Northwest Atlantic Fisheries) Subareas 3, 4, and 5 and Statistical Area 6 (SA 3-6) . 1). This assessment provided the basis for blishing the allowable level of catch in 1978 in the southern part of this area (SA 5-6) and was used by the N tional Marine Fisheries Service for its environmental act statement/preliminary fishery management plan the Atlantic mackerel fishery and by the Mid-Atlantic Fishery Management Council for its environ- tal impact statement/fishery management plan for fishery.

In previous years, this stock was managed through ICNAF, and assessments were completed jointly by scien- from various member nations within the ICNAF ssments Subcommittee. The last such assessment, on which the 1977 total allowable catch (TAC) was based, was made at the time of the Ninth Special ting of ICNAF held at Puerto de la Cruz, Tenerife, ary Islands, Spain, in November-December 1976 (ICNAF 1977). Separate assessments submitted by Ar erson et al.,[2] Isakov et al.,[3] and Ivanov[4] provided the basis for the 1976 assessment. In addition to this paper, catch projections for 1978 were provided by Isakov[5] and several unpublished Canadian reports (Hunt[6]; Lett and Hunt[7]; and Lett and Marshall[8]).

Data utilized here include international commercial and U.S. recreational catch statistics for 1961-77 and U.S. research vessel bottom trawl survey results for 1963-77. Results include estimates of fishing mortality, stock size, recruitment, and projected catch options for 1978, with the resulting spawning stock biomass levels for 1979.

METHODS

International commercial Atlantic mackerel catches for 1961-76 were obtained from *ICNAF Statistical Bulletins* published in 1963-77 (volumes 11-26), provisional catches for January-March 1977 were obtained from *ICNAF Circular Letters*, and catches for the remainder of 1977 were estimated.

Various marine angler surveys provided estimates of the 1960, 1965, 1970, 1974, and 1976 U.S. recreational catches of Atlantic mackerel (Clark 1962; Deuel and Clark 1968; Deuel 1973; Deuel[9]; Christensen et al.[10]).

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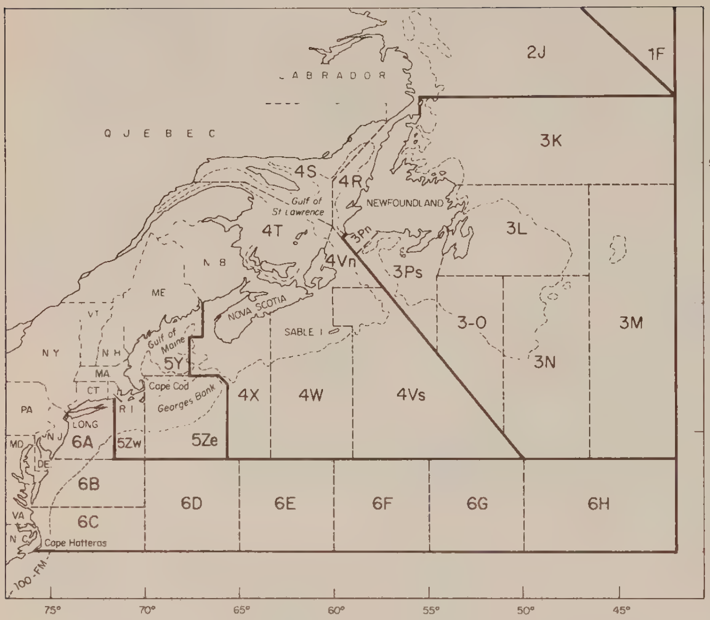

Figure 1.—Northwest Atlantic from North Carol to Labrador showing ICNAF Subareas 3, 4, and 5 a Statistical Area 6.

Catches in the intervening years were estimated by assuming that the ratio between catch and stock biomass from cohort analysis using only commercial data (ICNAF 1977) in each of the above years was the same in the preceding and succeeding 2 yrs, with the exception that the mean of the 1970 and 1974 ratios was used for 1972, and the mean of 1974 and 1976 was used for 1975.

The 1962-75 numbers at age from the commercial catch were taken from Anderson et al. (see footnote 2). The 1976 numbers at age were revised from those used in the last ICNAF assessment (ICNAF 1977). The general procedure used previously was to: 1) apply the length frequencies and age-length keys reported by individual countries to their catches to obtain numbers at age by country, 2) combine all such numbers at age for respective countries, and 3) prorate the summed numbers at age upwards to include catches from countries lacking sampling data. However, since significant differences were evident among age-length keys submitted by various countries for 1976 (Anderson et al.[11]), it was decided to combine country age-length keys by quarter. The procedure used was to: 1) determine numbers at length by country by month from available length frequencies and corresponding catches, 2) combine the numbers at length by quarter and prorate upwards to include country catches lacking sampling data, 3) apply the combined quarterly age-length key to the quarterly numbers at length to obtain quarterly numbers at age, and 4) combine the quarterly numbers at age to obtain the annual numbers at age. The estimated numbers at age for 1977 were determined by applying the above procedure to the available January-March catch and sampling data and then prorating the results upwards include the catch expected to be taken during the mainder of the year. Numbers at age for the 1962-77 commercial catches were prorated upwards to include the added U.S. recreational catches.

Mean weights at age (Table 1) adopted by ICNAF (1974) and used in previous assessments were employ in the present analysis. These values were applied to t numbers-at-age catch data for 1962-77 to obtain calculated catches which were compared with the observed catches. These values were also applied to the stock s numbers at age calculated from cohort analysis to obt stock biomass values. The summed biomass values for each year were adjusted using the appropriate observed/calculated catch ratios. The mean weights at a were used unadjusted in the projections of catch a stock biomass for 1978-79.

Table 1.—Mean weights at age (kilograms) for Atlantic mackerel (ICNAF 1974).

Age	Mean weight	Age	Mean weight
1	0.095	6	0.506
2	0.175	7	0.564
3	0.266	8	0.615
4	0.350	9	0.659
5	0.432	10+	0.693

Stratified mean catch-per-tow (kilograms) indices for Atlantic mackerel were calculated from U.S. resea vessel spring (1968-77) and autumn (1963-76) bott trawl surveys conducted in SA 5-6 in which sampling is based on a stratified random design (Cochran 1953) and strata (Fig. 2) constitute different depth zones and ar (Grosslein 1969). Survey methods, procedures, and g

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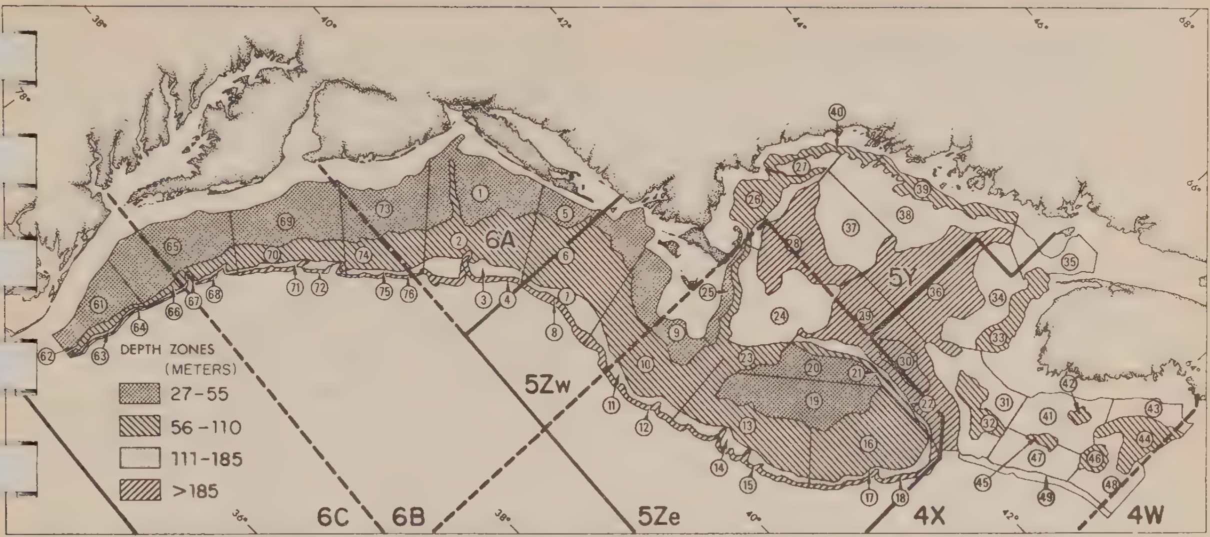
United States recreational fishery for Atlantic mackerel. Int. Comm. Northwest Atl. Fish. Res. Doc. 76/XII/142, Ser. No. 4038 (mimeogr.), 7 p.

[11] Anderson, E. D., C. F. Cole, and P. W. Wood. 1976. Variability in mackerel age data reported to ICNAF. Int. Comm. Northwest Atl. Fish. Res. Doc. 76/XII/146, Ser. No. 4042 (mimeogr.), 13 p.



ure 2.—Northwest Atlantic off the U.S. coast showing bottom trawl survey sampling strata and ICNAF Subarea 5 and Statistical Area 6.

were described by Grosslein.[12] Spring indices were ulated from catches in strata 1-25 and 61-76, and umn indices from catches in strata 1-2, 5-6, 9-10, 13, 16, 19-21, 23, and 25-26 (Fig. 2). All autumn catches and the 1968-72 spring catches were made with a No. 36 kee trawl, and the 1973-77 spring catches were made a larger No. 41 trawl. The 1968-72 spring catches were adjusted upwards to equivalent No. 41 trawl catches using a 3.25:1 ratio between the No. 41 and No. rawls (Anderson 1976) to establish a standardized e-series of catches. A ln $(x + 1)$ transformation of the station catches (kilograms) was made before calculation of the mean catch-per-tow indices. The ln indices were retransformed to the original scale for compatiity with other data used in the assessment. Retransformation was accomplished by the method described by ney (1941) using the equation:

$$\bar{y} = \exp\left(\bar{x} + \frac{S^2}{2}\right) - 1 \tag{1}$$

re $\bar{y}$ = retransformed catch per tow, $\bar{x}$ = ln catch per tow, and S^2 = population variance (ln scale).

Stratified mean catch per tow (numbers) by age for the 3-77 spring surveys was determined by applying agegth keys to the length frequency of the stratified mean catch per tow (Anderson et al. see footnote 2). Since age ples were not taken prior to the 1973 spring survey, the mean catch per tow for ages 0, 1, and 2 was determined prior to 1973. From the 1968-72 spring surveys, age 1 fish were defined as those measuring 22 cm less (fork length) and age 2 fish were defined as those suring 23-29 cm. Age 0 fish from the autumn surveys were defined as those measuring 23 cm or less.

Standardized U.S. commerical catch per day (metric tons) was calculated for 1964-76 as described by Anderson (1976).

Instantaneous fishing mortality (F) in 1977 was estimated using a technique developed by Anderson et al. (see footnote 2) which assumes a linear relationship between fishing effort and fishing mortality. The lack of an adequate measure of fishing effort or catch per effort was circumvented by calculating, as an index of fishing effort, the quotient of total catch divided by the spring survey catch per tow (Table 2). Because of the aberrant 1969 spring value (Anderson 1976; Anderson and Almeida 1977) and the year-to-year fluctuations in the remaining values, the 1968-77 time-series (Fig. 3) was smoothed by

Table 2.—Estimation of fishing mortality (F) in 1977 for the ICNAF Subareas 3, 4, and 5 and Statistical Area 6 Atlantic mackerel fishery.

Year	Spring survey catch/tow Actual[1]	 Calculated[2]	Catch[3] (t)	Fishing effort index[4]	Mean F[5] age 3+
1968	3.998	4.518	109,940	24,334	0.155
1969	0.065	3.199	165,113	51,614	0.144
1970	2.039	2.265	262,681	115,974	0.185
1971	1.969	1.604	403,675	251,668	0.268
1972	1.332	1.135	431,606	380,270	0.316
1973	0.748	0.804	429,250	533,893	0.451
1974	0.769	0.569	347,220	610,228	0.515
1975	0.255	0.403	293,740	728,883	0.532
1976	0.317	0.285	243,033	852,747	[6,7](0.626)
1977	0.199	0.202	92,000	455,446	[6](0.391)

[1] Stratified mean catch (kilograms) per tow (retransformed from ln to linear scale).

[2] Values predicted from exponential curve calculated using actual values for 1968-77 (except 1969). See Figure 4.

[3] Includes commercial and recreational catch.

[4] Catch divided by calculated spring survey catch/tow.

[5] Obtained from cohort analysis assuming F = 0.39 in 1977.

[6] Calculated from regression of fishing effort index on mean F for 1968-75: $Y = 0.121 + 0.00000059X$, $r = 0.991$.

[7] Actual value calculated from cohort analysis was 0.745, assuming F = 0.39 in 1977.

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osslein, M. D. 1974. Bottom trawl survey methods of the North- isheries Center, Woods Hole, Mass., USA. Int. Comm. Northwest Atl. Fish. Res. Doc. 74/96, Ser. No. 3332 (mimeogr.), 27 p.

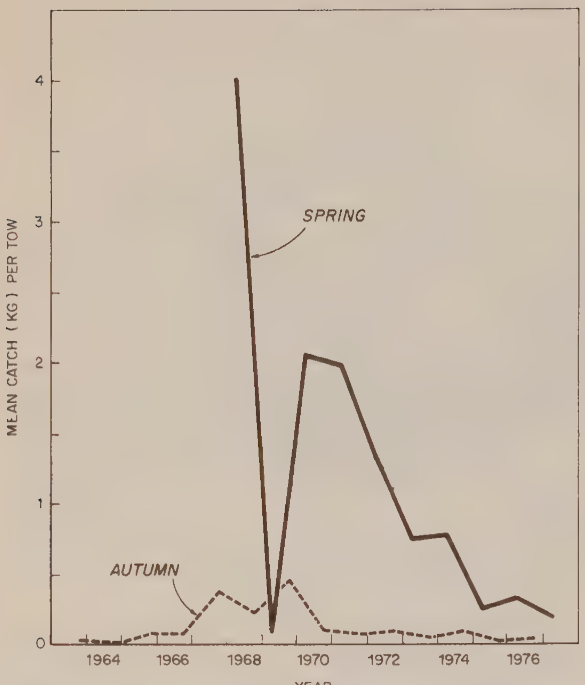


Figure 3.—Stratified mean catch (kilograms) per tow of Atlantic mackerel from the U.S. spring (1968-77) and autumn (1963-76) bottom trawl surveys.

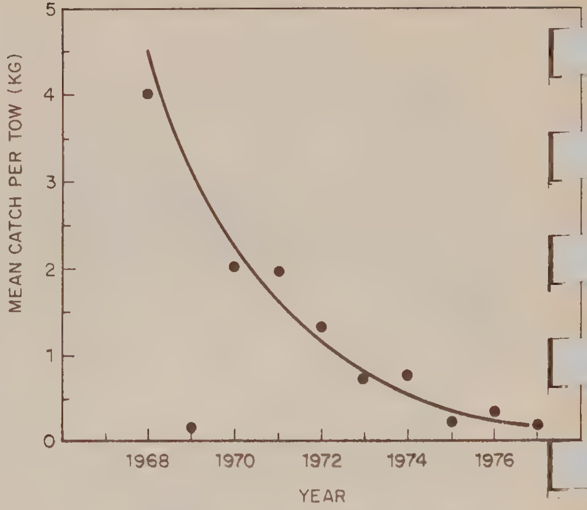


Figure 4.—Exponential curve calculated through 1968-77 time-series (1969 point omitted from calculation of curve) of spring survey c per-tow (kilograms) indices for Atlantic mackerel. Equation fo curve is: $\hat{Y} = 6.382 \exp(-0.345 X)$, $r = 0.976$.

fitting an exponential curve by least squares to the data points (Fig. 4), and the predicted values calculated the curve were used in place of the original value to determine the fishing effort index. Cohort analysis (Pope 1972) was performed using $F = 0.30$ for ages 4 and

Table 3.—Fishing mortality rates (F) for Atlantic mackerel in ICNAF Subareas 3, 4, and 5 and Statistical Area 6 derived from cohort analysis with natural mortality (M) = 0.30.

Year	Year														
class	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
1951	[1](.038)	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1952	.030	[1](.042)	—	—	—	—	—	—	—	—	—	—	—	—	—
1953	.088	[1](.042)	—	—	—	—	—	—	—	—	—	—	—	—	—
1954	.073	.019	[1](.039)	—	—	—	—	—	—	—	—	—	—	—	—
1955	.043	.006	[1](.039)	—	—	—	—	—	—	—	—	—	—	—	—
1956	.050	.006	.033	[1](.052)	—	—	—	—	—	—	—	—	—	—	—
1957	.051	.017	.321	.713	[1](.060)	—	—	—	—	—	—	—	—	—	—
1958	.127	.313	.374	.946	.288	.357	[1](.155)	—	—	—	—	—	—	—	—
1959	.030	.067	.066	.095	.163	.446	.156	.336	[1](.185)	—	—	—	—	—	—
1960	.006	.004	.014	.025	.054	.060	.013	.039	.090	[1](.268)	—	—	—	—	—
1961	.030	.010	.012	.016	.026	.040	.007	.042	.195	.262	[1](.316)	—	—	—	—
1962	—	.004	.032	.018	.023	.041	.119	.049	.369	.291	.500	[1](.451)	—	—	—
1963	—	—	.044	.017	.034	.032	.200	.059	.145	.150	.670	.892	[1](.515)	—	—
1964	—	—	—	.024	.042	.107	.351	.081	.142	.290	.239	.426	.575	[1](.532)	—
1965	—	—	—	—	.028	.045	.149	.249	.162	.342	.470	.449	.596	.503	[1](.745)
1966	—	—	—	—	—	<.001	.039	.136	.207	.472	.419	.283	.454	.474	2.002
1967	—	—	—	—	—	—	.027	.064	.181	.327	.441	.465	.580	.686	.888
1968	—	—	—	—	—	—	—	.003	.030	.097	.215	.409	.507	.536	.990
1969	—	—	—	—	—	—	—	—	.077	.173	.246	.410	.410	.523	.787
1970	—	—	—	—	—	—	—	—	—	.056	.091	.545	.430	.547	.598
1971	—	—	—	—	—	—	—	—	—	—	.015	.305	.598	.551	.708
1972	—	—	—	—	—	—	—	—	—	—	—	.168	.463	.469	.916
1973	—	—	—	—	—	—	—	—	—	—	—	—	.058	.452	.652
1974	—	—	—	—	—	—	—	—	—	—	—	—	—	[2].202	[2].330
1975	—	—	—	—	—	—	—	—	—	—	—	—	—	—	[2].018
1976	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
$\bar{F}$ (age 3+)[3]	.038	.042	.039	.052	.060	.111	.155	.144	.185	.268	.316	.451	.515	.532	.745

[1] Mean F for age 3+ assumed.

[2] Determined from assumed stock size and known catch.

[3] Weighted by stock numbers at age from Table 12.

[4] Age 4+.

in 1977 with instantaneous natural mortality (M) = 0.30 l ages (ICNAF 1974). This level of F was chosen as a approximation since the fishing effort index in 1977 was about half the 1976 index implying a similar reduction in fishing mortality from earlier estimates for 1976 of t 0.60-0.70. A linear regression between the 1968-75 ng effort indices and the mean F values for ages 3 and older from the cohort analysis predicted an F of 0.374 for 1977 based on the fishing effort index for 1977. A sec- cohort analysis was performed using 0.38 as the ter- l F in 1977. A second linear regression using the revised F values from this cohort analysis predicted F = 0.389 for 1977. A third cohort analysis was performed us- = 0.39 for 1977 (Table 3). A third linear regression predicted F = 0.391 for 1977 (Table 2, Fig. 5); therefore, F = 0.39 was accepted as the best estimate.

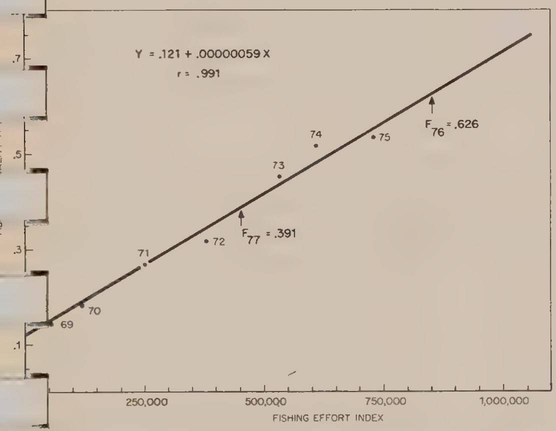


Figure 5.—Relationship between fishing mortality for Atlantic mackerel from cohort analysis and fishing effort derived from g survey catch per tow and total catch.

Power curve relationships, fitted by least squares, be- 1) autumn survey catch per tow (numbers) at and year-class size at age 1 determined from cohort analysis for 1963-73 (Table 4, Fig. 6), 2) spring survey catch per tow at age 1 and year-class size at age 1 for 73 (Table 5, Fig. 7), and 3) spring survey catch per tow at age 2 and year-class size at age 2 for 1966-73 (Table 5, Fig. 8) were used to estimate the sizes of the 76 year classes.

age groups incompletely recruited to the fishery, the ratio of fishing mortality at each such age to fishing mortality of fully recruited ages (the latter considered to be the mean F for ages 3 and older) was used as a ure of partial recruitment to the fishery. Partial recruitment coefficients were calculated for ages 1 and 2 for calendar years 1962-77.

e-specific F and stock size (N) values were deter- d for 1962-77 using cohort analysis. The value for N at each age in 1978 was calculated using the relationship

$$N_{i+1} = N_i e^{-Z_i} \qquad (2)$$

Table 4.—Catch per tow (number) of age 0 Atlantic mackerel from the U.S. autumn bottom trawl surveys (strata 1-2, 5-6, 9-10, 13, 16, 19-21, 23, 25-26) and year-class size (millions of fish) at age 1 from cohort analysis.

Year class	Autumn survey age 0	Cohort analysis age 1
1963	0.087	429.5
1964	0.022	542.2
1965	0.134	1,212.9
1966	0.170	3,165.3
1967	15.709	7,786.5
1968	0.215	3,114.3
[1]1969	38.504	3,244.9
1970	0.027	1,657.5
1971	0.517	1,711.9
1972	0.119	1,212.6
1973	0.339	1,981.2
1974	0.648	[2](2,515.6)
1975	0.012	[2](614.3)
1976	0.000	[2](0)

[1] Not used.

[2] Calculated.

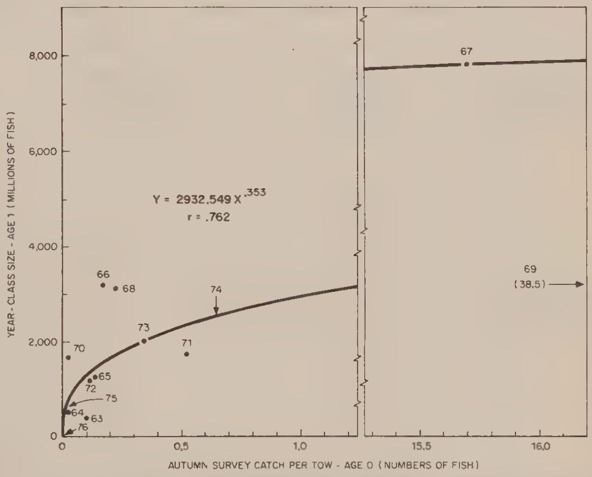


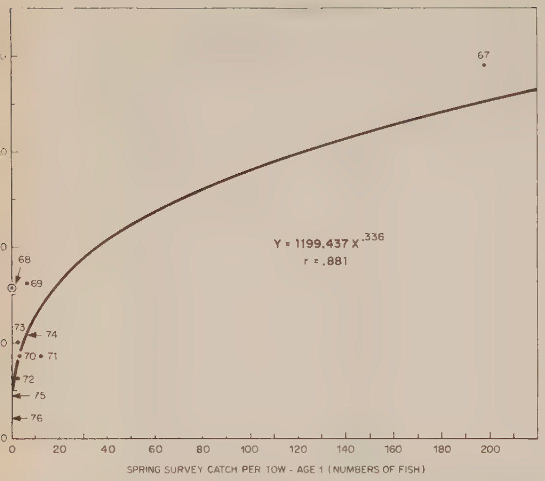
Figure 6.—Power curve relationship between Atlantic mackerel year-class size at age 1 from cohort analysis and autumn survey catch per tow at age 0. The 1969 point was not used in calculating the curve.

Table 5.—Catch per tow (number) of age 1 and 2 Atlantic mackerel from the U.S. spring bottom trawl surveys (strata 1-25, 61-76) and year-class size (millions of fish) at ages 1 and 2 from cohort analysis.

	Age 1		Age 2	
Year class	Spring survey	Cohort analysis	Spring survey	Cohort analysis
1966	—	3,165.3	21.661	2,344.1
1967	197.993	7,786.5	[1]1.190	5,617.3
1968	[1]0.299	3,114.3	12.435	2,300.1
1969	6.208	3,244.9	13.390	2,226.5
1970	2.954	1,657.5	5.545	1,161.4
1971	12.093	1,711.9	6.683	1,248.9
1972	1.949	1,212.6	0.749	759.4
1973	2.067	1,981.2	1.101	1,385.1
1974	5.330	[2](2,103.9)	4.928	[2](1,488.3)
1975	0.447	[2](915.3)	0.254	[2](651.8)
1976	0.043	[2](416.9)	—	—

[1] Not used.

[2] Calculated.



ure 7.—Power curve relationship between Atlantic mackerel r-class size at age 1 from cohort analysis and spring survey h per tow at age 1. The 1968 point was not used in calculating curve.

ere Z = instantaneous total mortality = $F + M$. Catch weight) options for 1978 were calculated for a range of alues by applying mean weights at age to the catch at in numbers (C_i) determined using the catch equa- n:

$$C_i = N_i \frac{F_i}{Z_i} (1 - e^{-Z_i}) \qquad (3)$$

l summing over all ages. Resultant stock sizes at age 1979 were determined using Equation (2).

RESULTS

tch

Table 6 contains a summary of annual Atlantic mack- l catches by the United States, Canada, and other intries during 1961-77. International catches in- ased from 13,700 t in 1961 to 431,600 t in 1972 and n declined to 243,000 t in 1976. United States nmercial catches varied from 900 to 4,400 t during this iod and averaged 2,300 t/yr. Estimated U.S. recrea- nal catches increased from 6,800 t in 1961 to a high of 300 t in 1969 and then declined to 5,000 t in 1976; the rly average for the period was about 15,000 t. Cana- n catches ranged between 5,500 and 21,200 t and eraged 12,600 t.

A total allowable catch (TAC) of 105,000 t was ocated by ICNAF for the international commercial hery in 1977. The provisional reported catch for nuary-March was 52,114 t (Table 7). Because of the nsiderable reduction in TAC from 1976 (310,000 t) and high demand for Atlantic mackerel by the distant- ter fleets, it was assumed that all countries, except nada, the United States, and "Others," would harvest eir full catch allocations during the remainder of 1977. sed on past performance, the Canadian catch was con-

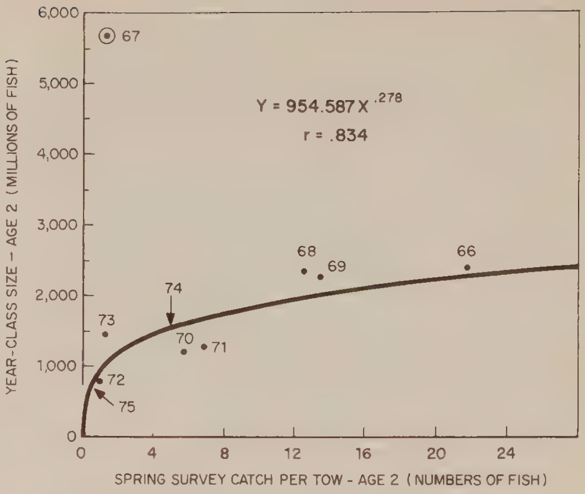


Figure 8.—Power curve relationship between Atlantic mackerel year-class size at age 2 from cohort analysis and spring survey catch per tow at age 2. The 1967 point was not used in calculating the curve.

Table 6.—Atlantic mackerel catch (metric tons) from ICNAF Subareas 3, 4, and 5 and Statistical Area 6 during 1961-77.

Year	United States Commercial	 Recreational	Canada	Other countries	Total
1961	1,361	6,828	5,459	11	13,659
1962	938	8,698	6,801	175	16,612
1963	1,320	8,348	6,363	1,299	17,330
1964	1,644	8,486	10,786	801	21,717
1965	1,998	[1]8,583	11,185	2,945	24,711
1966	2,724	10,172	11,577	7,951	32,424
1967	3,891	13,527	11,181	19,047	47,646
1968	3,929	29,130	11,134	65,747	109,940
1969	4,364	33,303	13,257	114,189	165,113
1970	4,049	[1]32,078	15,690	210,864	262,681
1971	2,406	30,642	14,735	355,892	403,675
1972	2,006	21,882	16,254	391,464	431,606
1973	1,336	9,944	21,247	396,723	429,250
1974	1,042	[1]7,640	16,701	321,837	347,220
1975	1,974	6,503	13,544	271,719	293,740
[2]1976	2,345	[1]4,947	15,744	219,997	243,033
[3]1977	3,000	5,000	20,000	64,000	92,000

[1] From angler survey; remaining years estimated (see text).
[2] Provisional.
[3] Estimated.

Table 7.—Estimated Atlantic mackerel catches (metric tons) in 1977 by country from ICNAF Subareas 3, 4, and 5 and Statistical Area 6.

Country	Reported through March	Estimated remainder	Total	Allocation
Bulgaria	3,110	890	4,000	4,000
Canada	—	20,000	20,000	30,000
Cuba	683	1,317	2,000	2,000
F.R.G.	—	1,100	1,100	1,100
G.D.R.	7,981	4,419	12,400	12,400
Italy	50	250	300	300
Poland	17,167	3,033	20,200	20,200
Romania	—	1,100	1,100	1,100
Spain	10	—	10	—
U.S.S.R.	22,586	214	22,800	22,800
U.S.A. (comm.)	527	2,473	3,000	6,000
U.S.A. (rec.)	—	5,000	5,000	—
Others	—	90	90	5,100
Total	52,114	39,886	92,000	105,000

NOAA Technical Report NMFS SSRF-733

Possible Management Procedures for Increasing Production of Sockeye Salmon Smolts in the Naknek River System, Bristol Bay, Alaska

Robert J. Ellis and William J. McNeil

April 1979

U.S. DEPARTMENT OF COMMERCE
Juanita M. Kreps, Secretary
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Possible Management Procedures for Increasing Production of Sockeye Salmon Smolts in the Naknek River System, Bristol Bay, Alaska

ROBERT J. ELLIS and WILLIAM J. McNEIL[1]

ABSTRACT

About 35% of the Naknek River system is greatly underutilized by juvenile sockeye salmon, *Oncorhynchus nerka*. In two basins the cause seems to be a lack of spawning grounds, and in a third basin the cause may be too few spawners or poor quality spawning grounds. The annual yield of adult sockeye salmon to the fishery could probably be increased by about 200,000 to 300,000 fish by increasing the production of smolts. Artificial production of fry, along with improving or increasing the spawning environments, is recommended. The numbers of adult females, eggs, and fry required to fully seed the three underutilized basins are discussed. Attempts to increase the production of sockeye salmon in the Naknek River system must be accompanied by detailed biological studies to determine optimum seeding levels and establish cause-and-effect relations.

INTRODUCTION

he sockeye salmon, *Oncorhynchus nerka*, resources of tol Bay, Alaska, are large and valuable and have been heavily fished since about 1900 (Burgner et al. 9). The National Marine Fisheries Service (under ous names) began research on the freshwater and early marine life of the sockeye salmon in Bristol Bay before 1920, and since the early 1940's much of this work been done in the Naknek River system.

he studies on sockeye salmon of the Naknek system have included most aspects of their freshwater biology, both biological and physical. Much is known about fac- that appear to limit the number of young salmon duced by the system and the number of returning adults (Burgner et al. 1969). Within broad limits, the number of returning adults produced in seawater in- ses as the number of young leaving freshwater as lts increases. In contrast, above a certain minimum, the number of smolts produced in freshwater appears to independent of the number of parent spawners— lt production is limited by freshwater spawning or nursery areas.

In this paper we briefly review information available in literature on 1) physical aspects and relative pro- tivity of the various lakes of the Naknek system, 2) abundance and distribution of spawning grounds and spawning adults, and 3) abundance, distribution, and vth of young sockeye salmon and associated species of We then consider factors that appear to be limiting production of juvenile sockeye salmon in the Naknek system and suggest management procedures that might significantly increase the production of smolts (juveniles going to the ocean).

PHYSICAL ASPECTS AND PRODUCTIVITY OF LAKES

In freshwater, juvenile sockeye salmon typically occupy four successive habitats for varying periods: spawning gravels of streams or lake beaches for several months, littoral of lakes for a few weeks, open-water areas of the lakes for several months to 2 or 3 yr, and an outlet river through which the smolts travel for a few hours or days to reach the ocean. Two factors seem most likely to limit the production of smolts: the quantity and quality of spawning grounds, which may limit the number of fry produced, and the productivity of the pelagic waters of the lakes where juvenile salmon do most of their feeding and growing.

The Naknek system consists of four major lakes—Coville, Grosvenor, Naknek, and Brooks—and an outlet stream that connects these lakes to the ocean—Naknek River (Fig. 1). Naknek Lake differs from the others in that it consists of five regions which appear to be physically and biologically discrete. These regions are treated as separate basins in our research—Iliuk Arm, South Bay, West End, North Arm, and Northwest Basin. Because of their relative locations and to facilitate our discussion in this paper, we designate five of these lakes or basins as main-stem basins and three as external basins (Table 1). Two high mountain lakes, Hammersly and Murray, are tributary to Coville Lake and receive only a few adult sockeye salmon each year so they are not considered here. In general the lakes of the Naknek system are deep, have little littoral area, and are oligotrophic (Burgner et al. 1969). The portion of each lake

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[1] Northwest and Alaska Fisheries Center Auke Bay Laboratory, nal Marine Fisheries Service, NOAA, P.O. Box 155, Auke Bay, 9821.

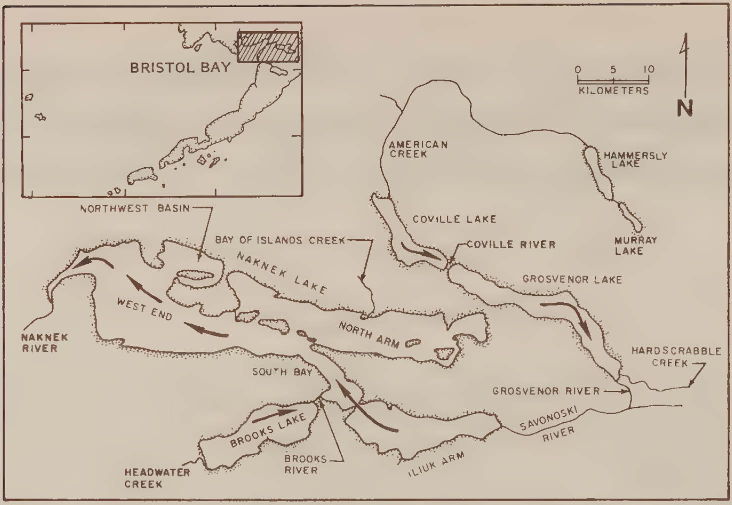
BRISTOL BAY
0 5 10
KILOMETERS
N
AMERICAN CREEK
HAMMERSLY LAKE
NORTHWEST BASIN
COVILLE LAKE
BAY OF ISLANDS CREEK
COVILLE RIVER
MURRAY LAKE
NAKNEK LAKE
GROSVENOR LAKE
WEST END
NORTH ARM
NAKNEK RIVER
HARDSCRABBLE CREEK
SOUTH BAY
GROSVENOR RIVER
SAVONOSKI RIVER
BROOKS LAKE
HEADWATER CREEK
BROOKS RIVER
ILIUK ARM

Figure 1.—Naknek River system, Alaska, showing the five main-stem lake basins (Coville and Grosvenor Lakes, Iliuk Arm, South Bay, and West End) and the three external lake basins (North Arm, Northwest Basin, and Brooks Lake).

Table 1.—Total surface area and percentage of each major basin of the Naknek River system shallower than 5 m.

Lake or basin	Surface area (km² or 100 ha)	Percent littoral area (<5 m deep)
Main stem basins		
Coville Lake	33	39
Grosvenor Lake	73	10
Iliuk Arm	94	4
South Bay	74	10
West End	218	26
External basins[1]		
North Arm	182	11
Northwest Basin	41	30
Brooks Lake	75	1
Total	790	

[1] The total surface area of the external basins composes 37.7% of the total surface area of all of the lakes.

<5 m deep ranges from about 39% in Coville Lake to about 1% in Brooks Lake.

Sockeye salmon spawn in tributaries of each lake on some beaches, and in Naknek River; but the amount of spawning grounds and the numbers of spawners are proportional to the size of the lakes (Table 2).

ABUNDANCE OF JUVENILE SOCKEYE SALMON AND ASSOCIATED SPECIES

The apparent abundance of juvenile sockeye salmon and associated species in the Naknek system from 1961 to 1964 has been reported in detail (Ellis 1974). species of fish predominated—sockeye salmon; th spine stickleback, *Gasterosteus aculeatus*; ninespine stickleback, *Pungitius pungitius*; pygmy whitefish, *Prosopium coulteri*; and pond smelt, *Hypomesus oli*

Table 2.—Distribution of spawning grounds of sockeye salmon and reported escapements of adult spawners in basins of the Naknek system.

		Potential spawning grounds		Range in spawners[1]	
Basin or lake	Surface area (km²)	Total (ha)	Relative to size of lake (ha spawning ground/ km² lake area)	Total (thousands)	Relative to size of lake (thousands/ km² lake area)
Main stem basin					
Coville Lake	33	111	3.32	80-1,000	2.4-30.3
Grosvenor Lake	73	30	0.40	35	0.5
Iliuk Arm	94	34	0.37	—	—
South Bay	74	6	0.07	4-150	<0.1-2.0
West End	218	148	0.68	75-200	0.3-0.9
External basin					
North Arm	182	8	0.04	6-[2]300	<0.1-1.6
Northwest Basin	41	1	0.02	<1-5	<0.1-0.1
Brooks Lake	75	18	0.24	8-27	0.1-0.5

[1] From Ellis (1974) except North Arm and Northwest Basin.

[2] About 300,000 fish were observed in North Arm in 1969. (R. D. Dewey, Northwest & Alaska Fisheries Center Auke Bay Fisheries Laboratory, Natl. Mar. Fish. Serv., NOAA, P.O. Box 155, Auke Bay, AK 99821, pers. commun. June 1975.)

Sockeye salmon were widely distributed and relatively abundant throughout the system. The distribution of the species of sticklebacks approximated that of juve- sockeye salmon, and in some areas sticklebacks were more abundant than juvenile salmon. Pygmy whitefish and pond smelt were abundant in some basins but never ndant together—pond smelt were abundant in Coville Lake and pygmy whitefish in Brooks Lake and South Bay.

Our best measure of the actual abundance of juvenile keye salmon came from sampling with tow nets in the pelagic areas of each basin (Ellis 1974). The use of this gear to estimate abundance of juvenile salmon is docu- ted by Johnson (1956), Ruggles (1966), and Pella 8). Ellis found that the abundance of age 0 sockeye salmon decreased after midsummer in Coville and Grosvenor Lakes, increased in Iliuk Arm and South Bay, was so low or erratic in Brooks Lake, Northwest n, West End, and North Arm that changes appear to have no meaning (Fig. 2). A decrease in abundance of age 0 sockeye salmon after midsummer would be expected use normally mortality would exceed recruitment from spawning grounds and littoral areas. Some basins, Coville and Grosvenor especially, had very few age I fish, although they were common to abundant in others (Fig.

Water flows from one main-stem basin to the next (Coville Lake, Grosvenor Lake, Iliuk Arm, South Bay, West End) and a summer migration of age 0 sockeye on results in migration of large numbers of fish from Coville Lake through the sequence of basins (Ellis 1974). By late August the abundance of age 0 sockeye salmon in lle Lake had markedly declined and had increased uk Arm and South Bay (Fig. 2). The three external basins, North Arm, Northwest Basin, and Brooks Lake, are not included in this sequence of events but the role of End in the summer migration is uncertain. Rela- y few age 0 sockeye salmon migrate from Brooks Lake to South Bay in the fall.[2] The apparent abundance of e 0 fish in the external basins is relatively constant so low during the summer that no great number could be migrating out of the external basins or in from South Bay or West End.

determine relative numbers of the major species in elagic areas, we summarized the tow-net data for August 1961-63 (Table 3). The catches of species other than sockeye salmon were much more variable than the es of salmon. (Pygmy whitefish were rarely taken in ets. Indication of their considerable abundance in Brooks Lake and South Bay comes from otter trawls and gill nets.)

reduction in growth of juvenile sockeye salmon in systems has been associated with large numbers of sockeye salmon, alone or with other species (Foerster 1944; Johnson 1958; Krogius 1961; Burgner 1964; Narver Dahlberg 1964), but this association does not appear in the Naknek system (Ellis 1974). The three basins with the greatest numbers of all species of fish in the tow-net catches were those with age 0 sockeye salmon of average or greater than average length—Northwest Basin, West End, and Coville Lake (Table 3). It appears that competition for food or space did not result in a reduction in growth of juvenile sockeye salmon in the Naknek system. The mean fork lengths of age 0 sockeye salmon from the Naknek system on 1 September were generally equal to or greater than those of two other major river systems of Bristol Bay (Wood and Kvichak Rivers) for which we have comparable data (Burgner et al. 1969).

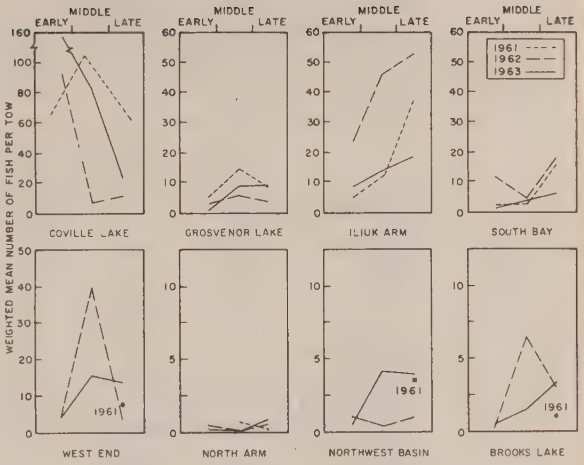

Figure 2.—Weighted mean number of age 0 sockeye salmon per standard tow by early (before 26 July), middle (26 July-10 August), and late (after 10 August) time periods in each lake of the Naknek River system, 1961-63. From Ellis (1974).

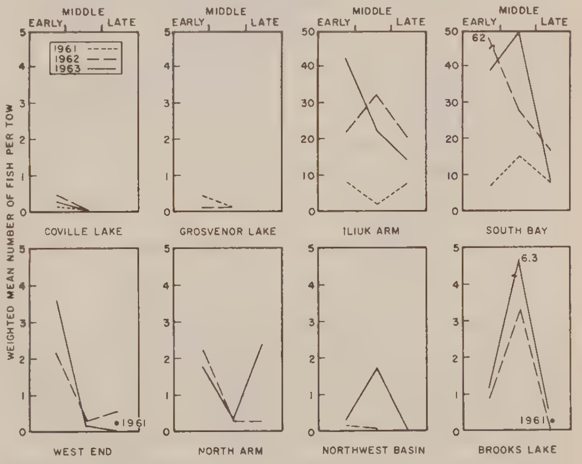

Figure 3.—Weighted mean number of age I sockeye salmon per standard tow by early (before 26 July), middle (26 July-10 August), and late (after 10 August) time periods in each lake of the Naknek River system, 1961-63. From Ellis (1974).

The rankings of abundance of age 0 sockeye salmon in the various basins in early summer relative to the rankings of area of potential spawning grounds (Table 4)

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[2] Hartman, W. L., W. R. Heard, C. L. Strickland. 1962. Red salmon stud at Brooks Lake Biological Field Station, 1961. Unpubl. manuscr., Northwest & Alaska Fisheries Center Auke Bay Fisheries Labora- Natl. Mar. Fish. Serv., NOAA, P.O. Box 155, Auke Bay, AK 99821.

Table 3.—Mean surface water temperatures in August, mean number of age 0 and age I sockeye salmon and of pond smelt and threespine and ninespine sticklebacks, and mean fork lengths of age 0 sockeye salmon in seven lakes of the Naknek River system, 1961-63.

Lake or basin	Mean surface water temperature[1] (°C)	Number of fish per tow[2]						Mean fork length of age 0 sockeye salmon[3] (mm)
		Mean for each species					Four species combined	
		Sockeye salmon Age 0	Sockeye salmon Age I	Pond smelt	Threespine sticklebacks	Ninespine sticklebacks		
Northwest Basin	14.4	30	0	46	35	29	140	56
Grosvenor Lake	10.8	8	0	0.5	0.5	0.5	8	48
Iliuk Arm	10.2	37	10	0.5	6	1	54	52
South Bay	11.7	10	9	0.5	19	5	43	53
West End	12.5	8	0.5	0.5	108	6	192	59
North Arm	11.8	1	1	0.5	1	0.5	3	52
Northwest Basin	14.5	5	0.5	2	548	37	590	54
Brooks Lake	11.9	3	0.5	0	0.5	0.5	3	53

[1] Mean of all observations made in each lake during tow netting in August 1961-63.

[2] Mean for 16 August to 1 September 1961-63, for species other than sockeye salmon and after 11 August for sockeye salmon.

[3] Mean for 20 August 1962 and 1963.

Table 4.—Abundance of spawning grounds and average catch per unit effort of age 0 sockeye salmon in early July 1961-63 in lakes of the Naknek River system.

Lake or basin	Area of potential spawning grounds per unit lake area (ha/km²)	Age 0 sockeye salmon per tow
Coville Lake	3.32	96
West End	0.68	3
Grosvenor Lake	0.40	3
Iliuk Arm	0.37	13
Brooks Lake	0.24	1
South Bay	0.07	5
North Arm	0.04	1
Northwest Basin	0.02	2

Table 5.—The systemwide mean catch per tow (weighted by area o each lake) for age 0 and age I sockeye salmon in the Naknek Rive system in August 1961-64 and resulting numbers of smolts pro Age 0 fish in August can become age I or age II smolts, but ag in August can become only age II smolts (rarely age III).

Age of fish and year of sampling	Fish in parent escapement (thousands)	Mean number of fish per tow-net catch	Smolts produced[1] (mi		
			Age I	Age II	Tota
Age 0					
1961	828.4	11.9	8.0	8.7	16.7
1962	351.1	13.2	6.0	5.0	
1963	723.1	8.8	2.2	9.9	
1964	905.4	23.0	14.7	6.1	20.8
Age I					
1961	2,231.8	1.9	—	8.5	
1962	828.4	4.7	—	8.7	
1963	351.1	3.2	—	5.0	—
1964	723.1	5.4	—	9.9	—

[1] Stewart, Donald M. (editor). 1969. 1967 Bristol Bay red smolt studies. Alaska Dep. Fish Game, Inf. Leafl. 134, p. 69.

within each basin were not correlated (at $P = 0.05$, Spearman rank correlation, Siegel 1956). However, Coville Lake had by far the highest ratio of spawning grounds to lake area and the greatest abundance of age 0 sockeye salmon in early July, and basins with the lowest proportions of spawning grounds had smallest catches of age 0 fish in the tow nets. The lack of significant correlation in all basins is likely due to many factors including: sampling error, annual variations in success of the various stocks, and incomplete knowledge of potential spawning grounds and their capacities to produce fry.

For the Naknek system, the abundance of age 0 sockeye salmon in late August between 1961 and 1964 was relatively constant. The mean number of fish per tow (weighted by surface area of each basin) varied by a factor of <3—from 8.8 to 23.0 (Table 5). In addition, the numbers of smolts produced by these age 0 fish (estimated in the Naknek River) were relatively constant. The parent escapements for the age 0 fish sampled from 1961 to 1964 ranged from 351,000 to 828,000 and for age I fish from 351,000 to 2,231,000 (Table 5).

From the foregoing discussion we see that the Naknek system has a relatively constant number of age 0 fish in the fall of each year and, similarly, a relatively constant number of smolts produced in the spring from 351,000 to 2.2 million parents (Table 5). It appears, however, that the three external basins are not supporting the density of age 0 sockeye salmon that could be possible. T the external basins, North Arm and Northwest I have by far the lowest spawning-area to lake-area ratios of the system which apparently results in too few fry to fully use the rearing areas. The third external Brooks Lake (fifth ranking in the system in ra spawning area to lake area), may have enough spawning grounds in Headwater Creek where the lake's major is produced, but the true capacity of this stream known.

PREDATION AS A LIMITING FACTC

Predation has been considered both significant in limiting the number of sockeye salmon smolts produced (Foerster and Ricker 1942; Rounsefell 1958) and ir ficant (DeLacy and Morton 1943; Roos 1959). species of fish and bird predators occur in the Naknek system but they appear to have little effect on the number of smolts. The best example of this little ef the large number of smolts per spawner produced

961 escapement. This escapement was relatively small 351,000), but about two-thirds of the spawners went to permost spawning grounds of the system—Amer- reek. As a consequence most of the progeny of the scapement had to run the gamut of predators to reach e ocean. Even so, the number of smolts produced per n the parent escapement was about 32, the high- e recorded between 1956 and 1963. Thus, a large te of production can occur in this system despite maxi- exposure to predation.

RATIONALE FOR INCREASING PRODUCTION OF SMOLTS

It appears that significantly more sockeye salmon could be produced in the Naknek system if pro- of fry in the three external basins (Brooks Lake, orth Arm, and Northwest Basin), which now support latively few juveniles, could be increased. Brooks lake intermediate ratio of spawning ground to lake ut the only way of increasing the escapement to eadwater Creek (the major spawning ground) is by lectively protecting its stock from the fishery. Since the o Naknek River occurs over a short period (Straty it may not be feasible to protect one stock with- ıt a closure of the entire fishery. Even if selective pro- of stocks were possible, increasing the escape- f spawners to North Arm and Northwest Basin oul probably not increase their fry production be- ıuse of limited spawning grounds. Therefore, the need er methods of increasing production of juveniles obvious—i.e., a selective increase in survival of me stocks from egg to fry via a hatchery system or ar- ficial spawning channels. Rationale for an enhance- rogram will now be developed.

pawning Populations and Sex Ratios

best estimates of the capacities of the Naknek and of the three external basins in particular to roduce fry can be determined from past escapement The annual escapements of adult sockeye salmon Naknek system averaged about 994,000 fish for the ears 1956-69 (Parker 1974). For Brooks Lake, unpub- shed observations by the National Marine Fisheries for the years 1957-67[3] reveal that an average of 21,000 adults spawned annually in the lake or its ibutaries (Table 6). For North Arm the average number spawning adults is assumed to be about 2% of the total ment to the Naknek system (an average of 20,000 nd for Northwest Basin the number is assumed to e about 0.2% (an average of 2,000 fish). These assumed tages are based on the respective percentages of al spawning area in each basin.

Table 6.—Number of adult sockeye salmon spawning[1] in Brooks Lake and tributaries and the percentage of females, 1957-67.

Year	Number of spawners	Percentage of females
1957	28,813	49.7
1958	13,418	26.5
1959	21,849	27.8
1960	12,361	28.0
1961	7,942	53.4
1962	27,204	39.7
1963	9,904	31.3
1964	19,068	29.8
1965	15,383	26.7
1966	35,953	35.4
1967	43,974	39.3
Mean	21,443	35.2

[1] Total count of adults passed into Brooks Lake at Brooks River weir less number counted back downstream (data derived from Dewey et al. see text footnote 3).

Although stocks of sockeye salmon spawning in the Naknek system exhibit variable sex ratios from year to year, males generally predominate. Some stocks, such as Brooks Lake, have a strong dominance of males in most years (Table 6), whereas others, as illustrated by American Creek (which flows into Coville Lake), exhibit a weak dominance of males (Table 7). On the basis of these data, we assumed a sex ratio of 40 females/100 spawners in estimating various factors related to the production of sockeye salmon in the Naknek system.

Table 7.—Number of adult sockeye salmon entering American Creek (Coville Lake) and the percentage of females, 1961-72. (Data from Dahlberg see text footnote 4).

Year	Number of adults	Percentage of females
1961	217,824	53.0
1962	84,332	46.1
1963	63,855	33.1
1964	50,385	30.1
1965	—	—
1966	99,712	34.6
1967	109,492	60.0
1968	121,324	32.4
1969	99,619	34.6
1970	77,468	24.1
1971	284,725	61.8
1972	99,562	43.1
Mean	118,936	47.8

Fecundity

The fecundity of sockeye salmon in the Naknek system appears to vary around an approximate average of 4,000 eggs/female. For example, Dewey et al. (see footnote 3) counted an average of 3,950 eggs/female (range 3,668-4,336 eggs) from Brooks Lake samples from 1957 through 1967. Dahlberg[4] reported an average of 4,651 eggs/female at American Creek (Coville Lake) and 3,553 eggs/female at Miss 42 Creek (Northwest Basin) in 1972.

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[3] Dewey, R. D., S. Tsunoda, and W. L. Hartman. 1971. Naknek system d salmon investigations, 1966-67. Unpubl. manuscr., 44 p. Northwest & isheries Center Auke Bay Laboratory, Natl. Mar. Fish. Serv., .O. Box 155, Auke Bay, AK 99821.

[4] Dahlberg, M. L. 1972. Studies of sockeye salmon in the Naknek River system, 1972. Unpubl. manuscr., 114 p. Northwest & Alaska Fisheries Center Auke Bay Fisheries Laboratory, Natl. Mar. Serv., NOAA, P.O. Box 155, Auke Bay, AK 99821.

Egg-to-Fry Survival

Ten estimates of survival from potential egg deposition to fry emigration have been made in three streams in the Naknek system (Table 8). The number of fry entering nursery lakes averaged nearly 9% of potential egg deposition.

Table 8.—Estimated survival of sockeye salmon from potential egg deposition to fry emigration in three spawning streams in the Naknek River system.[1]

Stream	Number of observations	Percentage survival Mean	Percentage survival Range
Hidden Creek (Brooks Lake)	5	10.1	6.6-13.7
One Shot Creek (Brooks Lake)	1	8.5	—
American Creek (Coville Lake)	4	7.3	0.7-12.0
Mean		8.8	

[1] Michael L. Dahlberg, Fisheries Research Biologist, Northwest & Alaska Fisheries Center Auke Bay Fisheries Laboratory, National Marine Fisheries Service, NOAA, P.O. Box 155, Auke Bay, AK 99821. Pers. commun. May 1976.

Fry-to-Smolt Survival

Assuming that the annual escapement was 994,000, 40% of the fish were females, and the average female carried 4,000 eggs into the system, the annual potential egg deposition averaged 1,590 million. The average number of sockeye salmon smolts emigrating from the Naknek River from 1956 to 1969, from which the average annual escapement was figured, was 12.2 million. From these assumptions we can calculate the average annual freshwater survival ($\hat{S}$) from potential egg deposition to outmigrating smolts as follows:

$$\hat{S} = \frac{12.2\ \text{(smolts)}}{1{,}590\ \text{(eggs)}} = 0.008.$$

Average fry-to-smolt survival can be approximated from the following relationship:

$$\hat{S} = \hat{S}_1 \times \hat{S}_2,$$

where $\hat{S}$ is the estimated total freshwater survival from potential egg deposition to smolt, $\hat{S}_1$ is the estimated egg-to-fry survival, and $\hat{S}_2$ is the estimated fry-to-smolt survival.

Using the values $\hat{S} = 0.008$, and $\hat{S}_1 = 0.09$, we calculate $\hat{S}_2$ to be

$$\hat{S}_2 = \frac{\hat{S}}{\hat{S}_1} = \frac{0.008}{0.09} = 0.09.$$

Thus, fry-to-smolt survival is estimated to average about 9%.

Desirable Fry Recruitment

There is no consensus on the level of sockeye sa fry recruitment to a lake that produces the maxi un outmigration of smolts. It is generally recognized that op timum fry recruitment will vary among lakes, de ing on various biotic factors such as primary anc ondary productivity and abiotic factors such as length c growing season. Data on primary productivity presente by Burgner et al. (1o69z for 10 western Alaska so salmon lake systems reveal that the Naknek syster intermediate rankings with regard to carbon fixation an standing crop of phytoplankton. However, the Nakne system ranks relatively low with regard to escapem spawners per 100 ha of lake area. Information i available to compare all basins within the Nakne system in regard to production of food for juvenil salmon and distribution of spawners.

The number of spawners, potential egg depositior an resultant smolt production for the Naknek system for th 14 brood years 1956-69 are shown in Figure 4. The h levels of smolt production appear to result from es ments of slightly more than 1 million adult sockey salmon, but for our estimates we used 1 million. Elli (1974) concluded that juveniles resulting from es ments of up to 1 million adults did not overburde food supply.

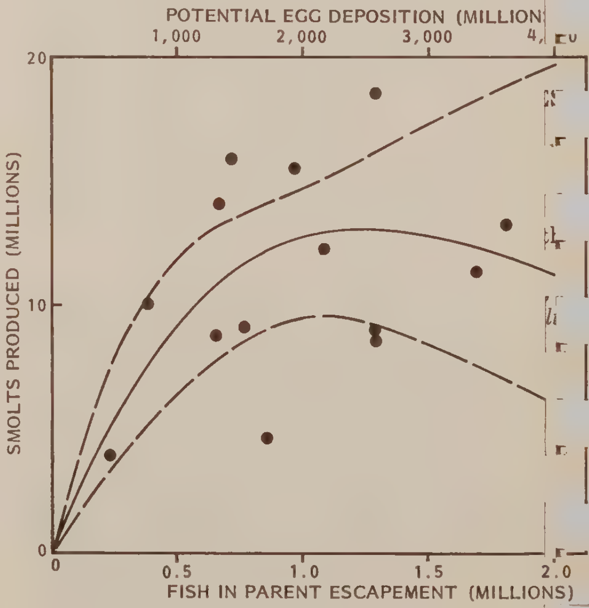

Figure 4.—Smolt production, parent escapement, and potent deposition in the Naknek system, 1956-69. Dashed line represents 95 confidence bounds of the expected smolt production. Modified fro figure 35 of Pella and Jaenicke (see text footnote 6).

Estimates of Current Fry Recruitment

Our estimates of current levels of fry recruitment t the various lake basins are based on estimates of sp escapement, sex ratio, fecundity, and egg-to-fry sur

We calculated average annual fry recruitment per 100
of lake area by dividing estimates of annual fry
ment (Table 9) by surface area (Table 1). The es-

ble 9.—Approximate number of fry recruited annually to lake
sins in the Naknek River system, assuming that 40% of the spawn-
females with an average of 4,000 eggs/female.

	Assumed adult escapement	Assumed average fecundity (number)	Assumed egg-to-fry survival	Calculated average annual fry recruitment (millions)
m lakes	951,000	1,600	0.09	136.9
rth m	20,000	1,600	0.09	2.9
rthwest Basin	2,000	1,600	0.09	0.3
oks Lake	21,000	1,600	0.09	3.0

ates for the combined main-stem lakes and for each
the external basins are:

Main-stem lakes	278,000
North Arm	16,000
Northwest Basin	7,000
Brooks Lake	40,000.

t approximation of the desirable number of addi-
nal fry that could be supported in the Naknek system
ned by determining the number of fry needed to
he average annual recruitment of fry in North
m, Northwest Basin, and Brooks Lake up to the level
imated for the main-stem lakes, i.e., 278,000 fry/100
le 10).

ble —Additional sockeye salmon fry that are desirable for lake
basins in the Naknek River system.

	Approximate fry recruitment (no./100 ha)	Target fry recruitment (no./100 ha)	Additional fry desired	
sin			Per 100 ha	For total basin (millions)
in stem lakes	278,000	278,000	0	0.0
m	16,000	278,000	262,000	47.7
t Basin	7,000	278,000	271,000	11.1
ake	40,000	278,000	238,000	17.8
otal				76.6

ional Spawners Required

With natural spawning, approximately 532,000 addi-
adults would be required in the combined escape-
to North Arm, Northwest Basin, and Brooks Lake
generate the potential for an additional 76.6 million
uits, i.e.,

North Arm	331,000
Northwest Basin	77,000
Brooks Lake	124,000
Total	532,000.

dequacy of Natural Spawning Grounds

o 5,000 female sockeye salmon spawners can be
modated on 1 ha of good quality spawning ground
urgner et al. 1969). With a sex ratio of 40 females/100
rs, 1 ha of spawning ground would accommodate
2,500 spawners (both sexes). Thus, at least 42.6 ha of spawning ground would be required for an additional 532,000 adults in the Naknek system. Under this assumption, the existing and required number of spawners and natural spawning areas in North Arm, Northwest Basin, and Brooks Lake (Table 11) lead us to conclude that:

1) The available natural spawning areas are inadequate for North Arm and Northwest Basin to meet the stated goals of fry recruitment, even if the desired spawner escapements could be provided.

2) The available natural spawning areas are adequate for Brooks Lake to meet the stated goals of fry recruitment. Factors which may now be limiting fry recruitment to Brooks Lake are underescapement of spawners and poor survival conditions in existing spawning areas or both.

Table 11.—Total existing and required number of spawners and spawning area for sockeye salmon in North Arm, Northwest Basin, and Brooks Lake.

	Number of spawners		Spawning area (ha)	
Basin	Existing	Additional required	Existing	Total required
North Arm	20,000	331,000	7.5	28.1
Northwest Basin	2,000	77,000	0.7	6.3
Brooks Lake	21,000	124,000	18.0	11.4

RECOMMENDATIONS AND CONCLUSIONS

Any plan to increase recruitment of sockeye salmon fry to North Arm, Northwest Basin, and Brooks Lake must satisfy the requirements of sockeye salmon for reproduction and time of entry of juveniles into the lake nursery area. Furthermore, such a plan should be economically feasible and will have to be integrated with resource management programs of the U.S. Park Service and the Alaska Department of Fish and Game. We consider four currently used methods to increase fry production in each of the three external basins: 1) Increase the escapement of spawners into already accessible spawning grounds, 2) provide spawners access to presently inaccessible stream areas by laddering impassable waterfalls, 3) construct spawning channels, and 4) construct hatcheries. Because of probable need to revise any method undertaken, all attempts to enhance the present stocks in the Naknek system should be carefully documented and evaluated.

Spawning channels to supplement natural recruitment of sockeye salmon fry to lakes have shown promise in some instances in British Columbia, and should be considered in the Naknek system. Assuming a satisfactory egg-to-fry survival of 70% in spawning channels (versus 9% in natural spawning grounds), channels with a capacity of approximately 27,000 female spawners (or about 67,500 total spawners with a 40:60 sex ratio) would be required. This would mean about 5.4 ha of spawning surface.

A hatchery capable of producing 76.6 million fry would probably cost less to construct than a spawning channel and would require much less space. A building to house the required incubators would encompass about 1,300 m.^{2} Provision of about 1,800 m^2 of exposed raceways might be desirable to allow for short-term rearing of hatchery fry until physical and biological conditions in the lake nursery waters become suitable. Although some physical factors favor a hatchery system, spawning channels would obviate some of the biological problems of hatcheries—especially genetic selection (matings occur naturally in spawning channels) and reduction in spreading of diseases. For example, IHN (infectious hematopoietic necrosis) virus is present in most stocks of sockeye salmon in Bristol Bay and will be an important factor in the success or failure of artificial enhancement projects in the area (Grischkowsky and Amend 1976).

North Arm

About 90% of the natural spawning in North Arm occurs in Bay of Islands Creek (Fig. 1) which drains a high tundra lake (Idavain Lake) and runs 27 km to North Arm. Upstream migration of salmon in Bay of Islands Creek is blocked by a waterfall 14 km from North Arm.

Lack of suitable natural spawning area is most likely the principal factor limiting production of sockeye salmon in North Arm. Nevertheless the present available natural spawning area (7.5 ha) should support up to 100,000 spawners of both sexes or about 40,000 females—recent escapements have been only about 20% of this number.

Construction of a fish passage facility at the waterfall on Bay of Islands Creek would provide salmon access to an additional 13 km of stream and could increase the available spawning area[5] in North Arm by about 50%. The feasibility of laddering the waterfall should be investigated because of its potential for a significant low-cost increase in natural production of fry.

If the waterfall could be laddered and escapement of sockeye salmon spawners to Bay of Islands Creek increased to 150,000 adults, fry production should be about

$$150{,}000 \text{ spawners} \times 0.4 \,\frac{\text{female}}{\text{spawner}}$$

$$\times\ 4{,}000 \,\frac{\text{eggs}}{\text{female}} \times 0.09 \,\frac{\text{fry}}{\text{egg}} = 21.6 \text{ million fry.}$$

The recruitment of fry to North Arm would be increased to 119,000 fry/100 ha, whereas the suggested target recruitment is 278,000 fry/100 ha (Table 10).

It seems doubtful, therefore, that Bay of Islands Creek has the potential to produce the additional fry needed to achieve the target density even with laddering of the waterfall. Therefore, consideration should be given to artificial propagation of fry. The minimum required capacity of either a spawning channel or a hatchery would be about 28.9 million fry annually.

A successful spawning channel or hatchery capable of producing 28.9 million fry could generate an additional 2.6 million smolts in the annual outmigration from Nor Arm. At least a 3 yr full-scale operation would be r quired to realize maximum smolt production fro lake. Should marine survival average 15% of t ditional fish from North Arm leaving Naknek Lake smolts (average survival of natural smolts from t Naknek system from 1956 to 1969 was about 19% a the nearby Ugashik system 12%) (Pella and Jaen an additional 390,000 sockeye salmon adults would be r cruited to the Bristol Bay fishing grounds. Three add tional years would be needed after maximum production is achieved before these artificially pro fish would become fully recruited to the fishery. It is lik ly that about 200,000 to 300,000 (50% to 70%) of the fi produced artificially in the Naknek system and ing to Bristol Bay would be caught in the fishery means that 117,000 or more of them would escape t fishery and return to Bay of Islands Creek, i.e., to t of the incubation facility. However, <30,000 of returning adults would be needed to restock a hatche facility (more would be needed for a spawning chann because of lower efficiency), and the remainder co allowed to spawn in Bay of Islands Creek. This wo sure almost full utilization of the natural spawning ar in addition to the artificial facility.

Northwest Basin

Natural spawning areas are too limited in Nort Basin to accommodate increased escapements o fish, and there are no opportunities to provide wi fi access to potential new spawning areas. The only obvio course of action for increasing recruitment of s salmon fry to Northwest Basin is through ha propagation, because creeks entering Northwest Bas are too small to satisfy the water requirements of spawning channel.

About 11 million hatchery-produced fry (see Ta would have to be added to the Northwest Basin achieve a target recruitment of 278,000 fry/km^2 of la nursery area. This would require a hatchery sim the facility already described for North Arm but one-third as large. However, costs of constructing ar operating such a facility on Northwest Basin wo considerably more than one-third the cost of a hatchery for North Arm. It would probably be mo ec nomical to enlarge a hatchery at North Arm to raise million fry instead of 30 million and to transplant lion fry annually to Northwest Basin. To reduce p changes in genetic makeup of stocks of Northwest Basi only adult fish randomly selected from Northwest Bas should be used to produce fry for that basin. Based same calculation used for North Arm, the 11 hatchery fry could be expected to yield about 75,000

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[5] Unpublished notes and stream survey data, Salmon Investigations (1961-1963). Unpaginated. Northwest & Alaska Fisheries Center Auke Bay Laboratory, Natl. Mar. Fish. Serv., NOAA, P.O. Box 155, Auke Bay, AK 99821.

[6] Pella, J. J., and H. W. Jaenicke. 1975. Some observations on the bi ogy and variations of populations of sockeye salmon of the Naknek ar Ugashik systems of Bristol Bay, Alaska, 1956-69. Processed report 133, Northwest & Alaska Fisheries Center Auke Bay Laboratory, Na Fish. Serv., NOAA, P.O. Box 155, Auke Bay, AK 99821.

00,000 adults to the fishery and about 45,000 to 75,000 pawners to Northwest Basin.

rooks Lake

T' known natural spawning area in tributaries to s Lake appears to be more than adequate for the umber of spawners required to fully stock the lake with ockeye salmon fry (Table 11). Inadequate fry recruit- n Brooks Lake appears to be the result of inade- escapement of spawners to the system rather than lack of sufficient spawning area.

The large terminal tributary to Brooks Lake, Head- Creek, is 80 km long and provides at least 15 ha of ing ground, all of which is accessible to salmon. scapements of sockeye salmon adults are typically 10,000 fish (see footnote 5), even though the stream easily accommodate 100,000 or more. Factors g the capacity of Headwater Creek to produce fry hould be determined before plans are developed to in- stocks of sockeye salmon in Brooks Lake through al propagation.

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Escape of King Crab, *Paralithodes camtschatica,* From Derelict Pots

William L. High and Donald D. Worlund

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Escape of King Crab, *Paralithodes camtschatica*, From Derelict Pots

WILLIAM L. HIGH and DONALD D. WORLUND[1]

ABSTRACT

Loss of 10% per season of pots (traps) in the Alaskan fishery for the king crab, *Paralithodes camtschatica*, has raised the question of possible loss of crabs and fishes to the derelict, or lost, pots which continue to fish. We conducted a series of experiments during 1974 and 1975 in which tagged king crab were placed in several types of pots and returned to the bottom (soaked) for periods of 1-16 days. As controls, we released some tagged king crab in Chiniak Bay, Kodiak Island, Alaska. Tagged crab missing from the pots at time of recovery were credited with escape.

The experiments demonstrated that 92% of undersize and 80% of legal-size king crab readily escaped the derelict pots. Mortality among crab held in pots for various experiments ranged up to 12%. Crab that escaped within 1-4 days were recovered by commercial fishermen at about the same rate as those released in Chiniak Bay near the experiment site. However, those released after a 10- to 16-day confinement were returned at a much lower rate. Some commercially valuable fishes—such as Pacific halibut, *Hippoglossus stenolepis*—were also caught in the experimental pots.

INTRODUCTION

King crab fishermen in Alaskan waters report losing 0% of their pots (traps) per season as a result of mishaps. Lost, or derelict, pots continue to at- act crabs and other animals for sometime. Animals un- le to escape from derelict pots eventually die. Species equently taken with king crab pots include the ab, genus *Paralithodes*; the snow (Tanner) crab, nus *Chionoecetes*; the Pacific halibut, *Hippoglossus enolepis;* and the Pacific cod, *Gadus macrocephalus.* rt of an effort to estimate the mortality of crabs er species in derelict pots, the National Marine sheries Service, in cooperation with the Alaska Department Fish and Game, conducted several experiments 1974 and 1975 in Chiniak Bay near Kodiak, aska. Our aim was to learn more about the signifi- nce of derelict pots on the king crab resource. Specif- we wished to determine: 1) the rate of escape of ze and legal-size king crab from four types of ts; 2) the effect of crowding upon escape; 3) the effect baited pots and the presence of dead crab upon escape d 4) the effects of confinement on subsequent re of tagged king crab.

We did not simultaneously conduct independent tests determine entry rates of crab into king crab pots. How- ab entry would not be critical if our study were to at all those entering would eventually escape.

If destruction of animals was found to be significant, en it would be appropriate to equip king crab pots with dable panel, that is, a portion of the enclosure would deteriorate rapidly and finally disintegrate en left in the sea unattended. Degradable panels (featuring web, secured by natural fibers) are already a standard part of sablefish, *Anoplopoma fimbria*, traps (Hipkins 1974) and have been proposed for king crab pots.[2] However, the cost in time to fishermen to maintain degradable panels is significant; therefore, they should not be required unless the benefits justify the expense.

HISTORY OF THE PROBLEM

Although some king crab fishing by U.S. fishermen began just before the Second World War (1941-45), it was not until nearly 1960 that the fishery was well established. The peak catch of 159.2 million pounds by about 300 vessels was reached in 1966. Fishing effort has continued to be high since 1965, but the catch has declined and was only 97.8 million pounds in 1975 (Rod Kaiser[3]).

Concern for the possible detrimental effects of derelict pots has been expressed in several quarters. Crab fishermen reported occasionally retrieving lost pots containing numerous crabs which they believed would die and attract other crabs, repeating the cycle until the trap was destroyed. Both crab and halibut fishermen observed that halibut often enter baited pots and are quickly attacked and killed by sand fleas (amphipods), ending up as bait within the pot for at least a short time.

Scientists studying gear operations expressed concern because available evidence suggested that heavy steel-framed pots with synthetic enclosure webbing would remain intact for some years. Occasionally, during research cruises, derelict pots were recovered which had apparently been submerged for 1 or more years. They

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est and Alaska Fisheries Center, National Marine Fisheries vice; NOAA, 2725 Montlake Boulevard East, Seattle, WA 98112.

[2] In 1976, the Alaska Board of Fisheries directed that after 1 July 1978, a degradable panel be placed in all king crab pots. 1976 Alaska Commercial Fishing Regulations, 1976-77 ed., p. 42.

[3] Rod Kaiser, Alaska Department of Fish and Game, Kodiak, AK 99615, pers. commun., September 1976.

contained numerous crabs and seemed to be in good working order.

Interviews with fishermen revealed common causes of pot loss including: 1) buoyline breakage from chafing or entanglement in vessel propellers; 2) buoy puncture by sea lions; 3) pots carried into deeper water when tangled in gear such as trawls, longline, or other pots; and 4) buoyline entanglement during set, so line is too short and buoys are carried under the surface.

MAGNITUDE OF POT LOSS

The year 1960 was the beginning of rapid growth in U.S. king crab fishing. By 1964, about 270 vessels participated in the fishery. The number of pots fished varied greatly among vessels because of variations in vessel size and changing Alaska regulatory limits for pots fished per vessel. In the 1969-70 season, 354 vessels fished an average of 70 pots each (Rod Kaiser, see footnote 3). Fishermen generally agree that about 10% of their pots are lost each season. Some vessels reported pot losses of up to 50%, but such losses were uncommon.

To develop an estimated number of lost pots, we
sume that 300 vessels fished an average of 60 po
per year from 1960 to 1975. About 10%, or 27,000
270,000 pots fished during the 15 yr may have bee
Based upon the engineering longevity estimate of 1
for pots (Richard McNeely[4]), we can assume tha
lost pots may still be fishing. The others would no
catch crabs because of damage by fishing gear—suc
trawl, longline, and other pots—or because of envi
mental conditions—such as pots settling into s
shallow depths (Rearden 1976). Sea lions could als
damaged the pots.

In view of those estimates, and from interviews
fishermen, we conclude that there are thousands
in fishing condition lying on commercial crab gr
Occasional derelict pot recoveries confirm that cr
continue to enter them (Fig. 1). The problem of d
pots, then, lies with the number of fishable pots a
mortality of crabs entering them.

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[4] Richard McNeely, Northwest and Alaska Fisheries Center, Nat
Marine Fisheries Service, NOAA, Seattle, WA 98112, pers. c
December 1976.

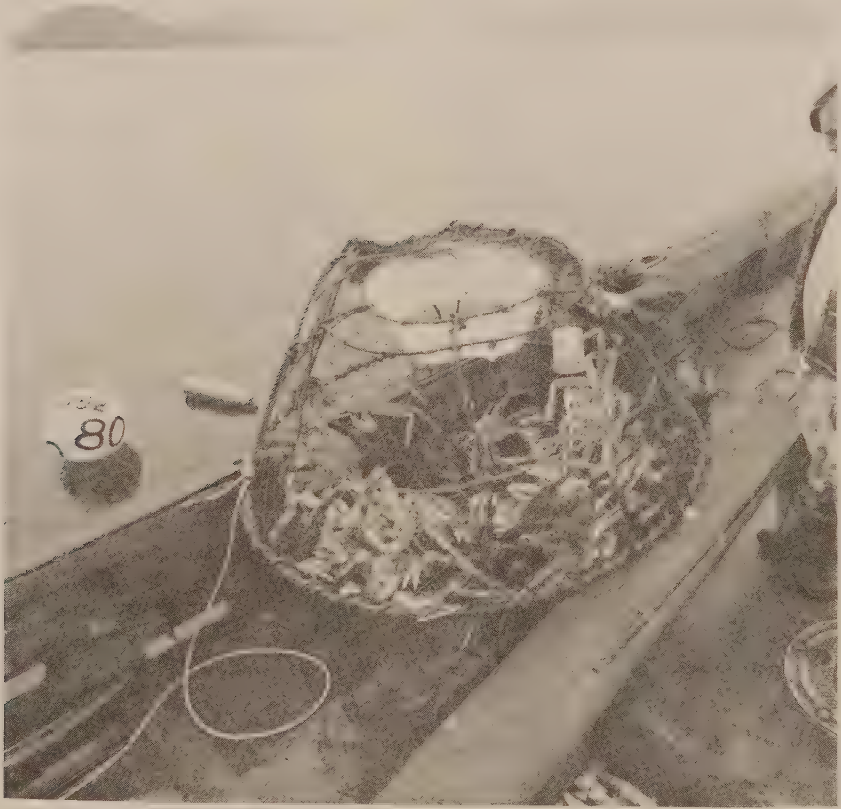

Figure 1.—This abandoned Japanese-type snow crab pot, recovered 3 mo after close of the commercial fishing season, contained 12 king crab and 14 snow crab. One of each species was dead.

EXPERIMENTAL DESIGN

e one of our objectives was to learn whether king uld escape from various styles of pots, we also nted to estimate the effect of confinement or possible luring escape on crab viability. Tagged undersize ab (120-139 mm eye socket to posterior margin of carapace) and legal-size king crab (150-169 mm long) e placed in pots and returned to the sea floor. Follow- edetermined "soak" (period on the bottom) of up ays, pots were recovered to identify those crab naining, including those alive or dead, and new untag- king crab that entered the pots during the soak. Tag- g crab were also released from the vessel into Bay (free-release) to permit observation of any ference in returns between 1) those confined to pots il their escape and 2) crab subjected only to the tag- rocess. Four factors—escape, mortality, new and tag returns—were then compared with gth of soak. Since each factor might be influenced by ign, we selected styles in use by Kodiak area en.

esults of preliminary experiments conducted in 1974 mpted us to expand the study during 1975 to include nd recovery data from other styles of pots. We ted to learn whether presence of bait (chopped ring in bait containers) or dead king crab influenced entry or escape rate.

urther estimate of effects upon viability caused nement, some tagged crab, remaining in study s that had been soaked for 10-16 days, were released he surface from recovered pots to observe their recov- —compared with crab that had escaped during

MATERIALS AND METHODS

Many styles of king crab pots are used in the Alaska ery regularly as well as experimentally by fishermen archers.

scription of Pots

ne principal types of commercial crab pots were ted to determine whether size, shape, or tunnel con- n might affect crab escapement. Whenever pos- ar and handling techniques were those used in commercial fishery so that derelict pot conditions ld be simulated.

ots were box-shaped (Fig. 2A). Pot dimensions -213 cm (6-7 ft) square and 76-99 cm (30-39 in) h. Weight varied between about 182 and 318 kg (400 700 lb) each, depending upon the size and amount of d. Tunnel entrance frames varied from 89 by 19 y 7$^{1}/_{2}$ in) to 102 by 20 cm (40 by 8 in). Several h sizes between 10 and 20 cm (4 and 8 in) were used various pots.

esting pyramid-shaped pot had a steel-framed cm (80 in) square with a top frame 122 cm (48 in) square, 61 cm (24 in) above the base (Fig. 2B). The frame was enclosed with 15-cm (6-in) mesh except for the fiberglass top and circular tunnel which provided a 43-cm (17-in) diameter entrance. This style pot is mostly used by small vessels having limited deck storage. Seven of these pots occupy a space 203 cm (80 in) square by 157 cm (62 in) high.

Ray Spagnola, master of the MV *Tammy* hired to fish the study pots, had some custom-made nesting pyramid pots which we designated as "radical pyramid pots" (Fig. 2C). This pot's dimensions were 213 cm (84 in) square at the base with a 122 cm (48 in) upper square frame. Vertical height was 86 cm (34 in). The tunnel consisted of a web-covered steel frame angled 29 cm (11$^{1}/_{2}$ in) down into the pot. Extra framing for a dumping door on one side caused the pots to be unbalanced. Part way through the experiment, counterweights were placed opposite the door.

Small, light-weight nesting conical pots, of the type used by Japanese fishermen for snow crab in the Bering Sea, were recently entered into use in the Kodiak area king crab fishery aboard small boats (Fig. 2D). These conical pots were 152 cm (60 in) in diameter at the base, tapering to 81 cm (32 in) at a height of 69 cm (27 in). A 23-cm (9-in) long tapered plastic collar diminishing from 53 cm (21 in) at the top to 41 cm (16$^{1}/_{4}$ in) at the orifice served as a tunnel. They were designed to be fished at intervals along a groundline, in contrast to heavy king crab pots which are fished individually from a buoyline.

Selecting, Handling, and Tagging Crab

Two sizes of king crab were selected, smaller than and larger than minimum commercial size of about 145 mm carapace length. Five female crab were included in the 1974 experiments, but the shells of most were too fragile to withstand the handling associated with tagging and return to pots. Consequently, females were excluded during 1975.

Crab for the experiments were captured in pots usually soaked 1-2 days in Chiniak Bay. Fishing depth ranged about 70-164 m (38-90 fathoms). The vessel moved the fishing gear within the central Chiniak Bay area to increase catch of crab in the desired size ranges and to remain near test pots already concentrated in one area.

Crab were inspected and measured after removal from fishing pots; rejected crab were immediately returned to the sea. A carapace dart tag was placed through the dorsal shell on the posterior left side (Powell 1964). Initially, a hole was punched through the shell to accommodate the nylon tag barb. The barb was then pushed through the shell hole to hold in place a colored plastic disk bearing a serial number and legend. Tagging was rapid, and tagged crab usually remained on deck less than 30 min before the filled test pot was set.

Test pots were balanced on the vessel rail, when filled with tagged crab, so they could be pushed over even though heavily weighted. Occasionally a crab was injured when one or more of its legs protruded through the meshes and were crushed between the pot frame and

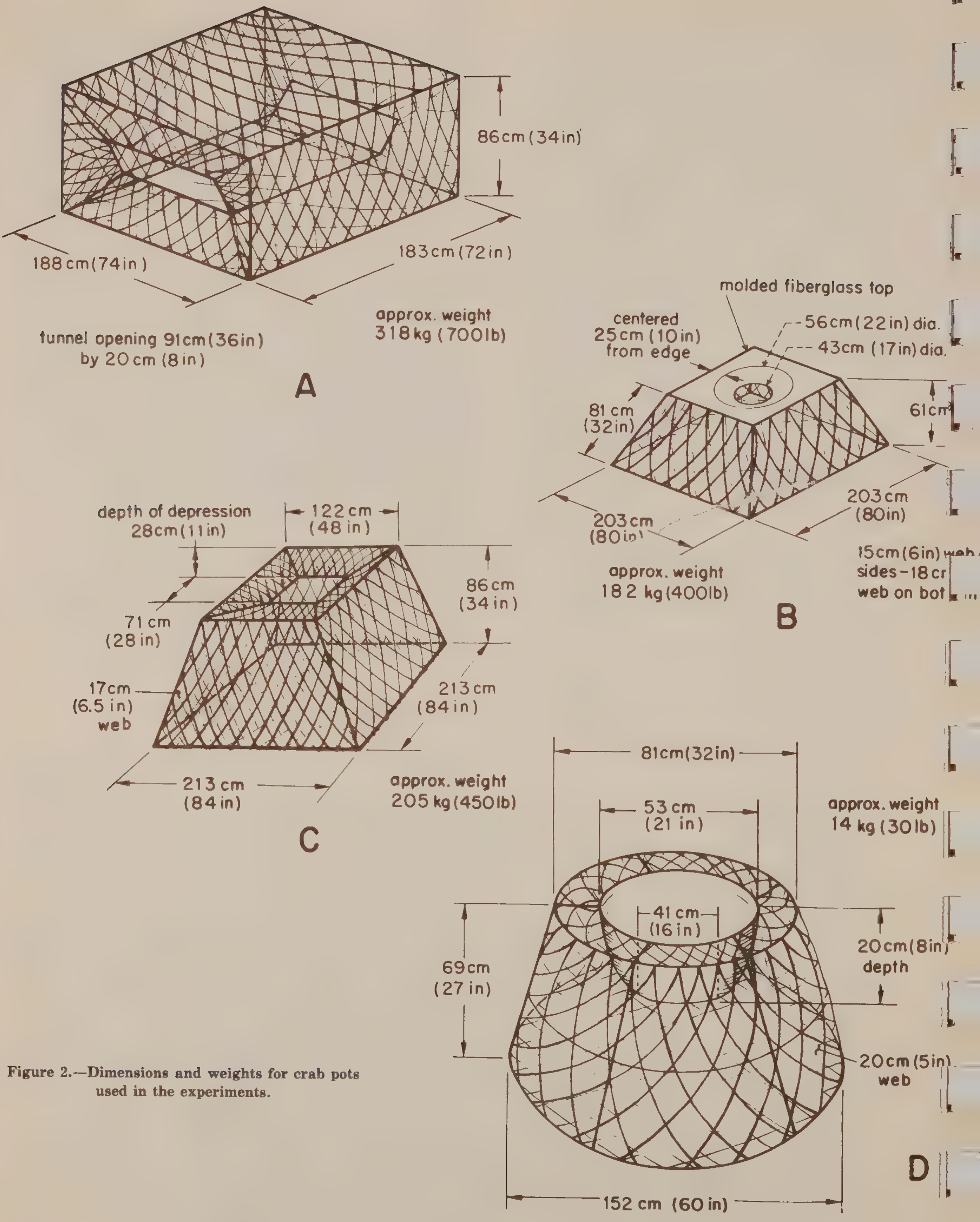
86cm (34in)
188cm (74in)
183cm (72in)
tunnel opening 91cm (36in) by 20cm (8in)
approx. weight 318kg (700lb)
A
molded fiberglass top
centered 25cm (10in) from edge
56cm (22in) dia.
43cm (17in) dia.
81 cm (32in)
61cm
203cm (80in)
203cm (80in)
approx. weight 182 kg (400lb)
15cm (6in) web
sides–18cr
web on bot
B
depth of depression 28cm (11in)
122cm (48in)
86cm (34in)
71cm (28in)
17cm (6.5in) web
213cm (84in)
213cm (84in)
approx. weight 205kg (450lb)
C
81cm (32in)
53cm (21in)
approx. weight 14kg (30lb)
41cm (16in)
69cm (27in)
20cm (8in) depth
20cm (5in) web
152cm (60in)
D

Figure 2.—Dimensions and weights for crab pots used in the experiments.

ship's rail. At the time of pot retrieval, dead crab found he pots were inspected to determine whether such in- es might have caused their deaths.

Unbaited Pot Experiment

scape rates were obtained by allowing pots containing tagged crab to soak for various intervals before retrieval. Tagged crab missing from the pot when it was overed were presumed to have escaped. Their subsequent recovery in the commercial fishery was compared with conditions of those released directly into Chiniak Bay. Recovery rates were expected to be similar if no in- y resulted from confinement or escape effort.

Box Shaped Pots

During 1975, 60 tagged crab (30 undersize and 30 legal size) were placed in each of 24 "standard" pots (Fig. 2). Groups of three pots were lifted after 1, 2, 3, 4, 7, 10, 15, 16 days. Six groups of four pots, set in 1974, did not e a prescheduled retrieval date except for the first four pots after 4 days. Since we did not know what escape rate to expect, each pot retrieval day (after the first) was ed upon the observed escapement at that time. We anticipated that retrieval for the six groups might take 40 days or more. Instead, they were lifted after 4, 6, 8, 10, 1 and 15 days.

Fiberglass Pyramid Pots

This test was limited in scope because our objective s simply to determine whether the escape rate was different from that of standard pots. Thirty undersize and 30 legal-size tagged crab were placed in each of 12 pots uped in pairs for 1-, 2-, 3-, 4-, 10-, and 16-day soaks.

Radical Pyramid Pots

Numbers of crab and soak durations were the same as for the fiberglass pyramid pots. Two tagged crab were erved floating out of the large top opening in these s just after the pots were pushed into the water. It is not likely many escaped in this way because the pots were heavier on the door side and tended to descend with e side up preventing crab from floating out the open- . After each pot reached the sea floor, tension was taken up on the buoyline to upright the pot. In spite of this maneuver, several radical pots remained on their es (indicated by stained web and steel), and escape- nt promptly approached 100% as crab could walk freely out the misplaced opening. Such "invalid" pots were deleted from the experiment.

Conical Snow Crab Pots

The Japanese-type pot was considerably smaller than e other pots. Consequently, only 15 undersize and 15 legal-size tagged crab were placed in each one (three groups of four pots were attached to groundlines at 18-m (10-fathom) intervals with single buoylines to the surface). As with the standard pots used in 1974, only the first group lift was scheduled after a 4-day soak. The initial escapement was of such magnitude that the remaining groups were lifted after 8-10 days on the bottom.

Crowding Experiment

Occasionally, pots are retrieved that are completely filled with crab. It is difficult to imagine how 200 or more adult crab could enter a pot or, once inside, effectively escape. The effect of crowding upon escape was tested in two groups of three standard box-shaped pots by placing 75 undersize and 75 legal-size tagged crab in each. A few more than the 150 crab could have been accommodated in the pots, but with more than that number some individuals could have fallen out through the tunnel during the setting process.

Baited Pot Experiment

Our objective was to determine whether bait (chopped herring or dead king crab) would motivate tagged crab to remain in pots longer than they would have otherwise, thereby causing increased mortality. Bait is either in the derelict pots at the time of their loss or is formed whenever animals die in the pots. Although it is an accepted fact that crabs are attracted to bait consisting of fish pieces, we did not know if king crab in baited pots would remain longer than those in unbaited pots or if dead king crab attract living crabs. Research conducted by Hancock (1974) with Australian lobsters gave indications that dead members of that species repel their living counterparts.

Standard baited pots were treated in a manner similar to that in experiments with unbaited pots. In one test, chopped pieces of Pacific herring, *Clupea harengus pallasi*, were placed in 1-qt plastic containers that had perforations to allow dispersion of solutes. These commercial style containers were hung in each of six pots with 60 tagged crab and set near other test pots. Soak periods were 1, 3, and 7 days. A second group of six standard pots were each filled with 60 tagged crab along with 15 freshly killed crab of assorted sizes. New crab entering these pots and those entering unbaited pots were recorded as were those tagged crab which remained—to provide an estimate of movement into and out of the pot groups.

Confined Crab Viability Experiment

Duration of confinement in pots was tested in two ways to learn if duration caused mortality or otherwise affected crab survival, even though the crab left the pots before death. First, crab mortalities that occurred during the various soak periods were tabulated and compared. Secondly, returns of tags from the commercial fishery for free-release crab served as controls and were compared with recoveries of crab that had escaped from the various test pots. A significant difference in recovery rates was accepted as reflecting causes associated with the confinement or escape effort.

If recovery were reduced for crab escaping the pots, then we would want to know if it were related to length of confinement. Our experimental procedure did not permit us to record exactly when a particular crab left a study pot. We were, however, able to obtain samples of crab that reflected short (1-4 days) and long (10-16 days) confinements.

Crab that had escaped from pots soaked only 1-4 days were recorded. Because the crab that left the pots after 10 days could not be recorded, we recorded tagged live crab remaining in long-soak pots at the time of their retrieval. Those crab that were apparently uninjured and viable were released, with the tag intact, in a manner similar to the free-released crab. Tag returns from the two groups were compared to determine whether those in the 10- to 16-day group had returns similar to those held 1-4 days.

We recognize certain limitations to this procedure, particularly the fact that those crab designated as "long soak" were subjected to one additional lift and further on-deck handling. Moreover, we could not assess the possible predation occurring during any of the short-ti periods that surface-released crab were returning to sea floor. However, no marine mammals were in the vicinity.

Incidental Catch Observations

Other animals captured in king crab pots may a suffer the consequences of long confinement. Both invertebrates and fishes were captured during our studies.

No attempt was made to establish escape rates snow crab, although they were in nearly every pot lift. Because snow crab are considerably smaller than king crab and scuba observations show them to be more active, it is likely that snow crab can readily escape k crab pots. They may not, however, easily escape fr snow crab pots.

Records were kept of our capture of fishes. Fishermen were interviewed to learn how frequently nontar species were captured in pots.

Table 1.—Escapement and soak time of undersize and legal-size king crab for various pot types.

Crab size and no. of days soaked	Standard pots (1974-75)		Radical pyramid pots		Fiberglass pyramid pots		Snow crab conical pots		Baited standard pots		Standard pots with dead crabs		Standard pots crowde	
	No. of pots	Avg. % escaping	No. of pots	Avg. % escaping	No. of pots	Avg. % escaping	No. of pots	Avg. % escaping	No. of pots	Avg. % escaping	No. of pots	Avg. % escaping	No. of pots	Avg escaping
Undersize (120-139 mm)														
1	3	31.1	2	73.3	2	11.9	—	—	2	40.8	2	47.4	—	—
2	3	51.6	2	40.4	2	17.2	—	—	—	—	—	—	—	—
3	2	65.9	1	73.1	2	22.3	—	—	1	82.1	—	—	—	—
4	5	64.3	2	27.1	2	37.5	4	26.7	—	—	2	76.3	—	—
5	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	4	78.2	—	—	—	—	—	—	—	—	—	—	—	—
7	3	76.6	—	—	—	—	—	—	2	91.2	2	76.8	3	96.
8	4	85.0	—	—	—	—	3	24.7	—	—	—	—	—	—
9	—	—	—	—	—	—	—	—	—	—	—	—	3	96.5
10	6	83.0	—	—	2	34.3	4	55.8	—	—	—	—	—	—
11	—	—	—	—	—	—	—	—	—	—	—	—	—	—
12	—	—	—	—	—	—	—	—	—	—	—	—	—	—
13	—	—	—	—	—	—	—	—	—	—	—	—	—	—
14	4	87.0	—	—	—	—	—	—	—	—	—	—	—	—
15	6	91.5	—	—	—	—	—	—	—	—	—	—	—	—
16	3	87.2	2	80.2	2	43.4	—	—	—	—	—	—	—	—
	43		9		12		11		5		6		6	
Legal (150-169 mm)														
1	3	26.4	2	71.7	2	23.2	—	—	2	21.6	2	28.4	—	—
2	3	37.8	2	47.4	2	56.4	—	—	—	—	—	—	—	—
3	2	37.0	1	65.5	2	51.2	—	—	1	—	—	—	—	—
4	5	41.3	2	55.2	2	50.4	4	46.3	—	89.3	2	51.4	—	—
5	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	4	51.8	—	—	—	—	—	—	—	—	—	—	—	—
7	3	53.1	—	—	—	—	—	—	2	68.5	2	55.5	3	84.6
8	4	71.3	—	—	—	—	3	49.1	—	—	—	—	—	—
9	—	—	—	—	—	—	—	—	—	—	—	—	3	85.7
10	6	69.4	—	—	2	41.0	4	71.2	—	—	—	—	—	—
11	—	—	—	—	—	—	—	—	—	—	—	—	—	—
12	—	—	—	—	—	—	—	—	—	—	—	—	—	—
13	—	—	—	—	—	—	—	—	—	—	—	—	—	—
14	4	67.7	—	—	—	—	—	—	—	—	—	—	—	—
15	6	75.4	—	—	—	—	—	—	—	—	—	—	—	—
16	3	69.0	2	67.2	2	54.2	—	—	—	—	—	—	—	—
	43		9		12		11		5		6		6	

RESULTS

ape From Standard Pots

Percentages of escapement of undersize and legal-size from the pots of various designs and configurations shown in Table 1.

Percentage escapement of legal and undersize crab from individual standard pots during various times up to 16 days is revealed in the combined data for 1974 and 1975 (Tables 2, 3). To describe the cumulative percentage escapement with time, the data were first transformed to arcsine values and an average computed for each duration of soaking time. Using the asymptotic

Table 2.—Escapement of legal-size king crab from standard pots (data from 1974 and 1975 combined).

nber days soaked	Percent escapement per pot	Arcsine percent escapement	Average arcsine	Average percent escapement[1]
1	3.33	10.47	28.09	22.2
	62.07	52.00		
	13.79	21.81		
2	20.00	26.56	36.96	36.2
	10.00	18.44		
	83.33	65.88		
3	46.43	42.94	37.32	36.8
	27.59	31.69		
4	33.33	35.24	39.88	41.1
	26.67	31.11		
	48.28	44.03		
	48.28	44.03		
	50.00	45.00		
6	43.33	41.15	46.22	52.1
	37.04	37.47		
	76.92	61.27		
	50.00	45.00		
7	53.85	47.21	46.80	53.1
	65.38	53.97		
	40.00	39.23		
8	76.67	61.14	59.24	73.8
	48.28	44.03		
	62.50	52.24		
	96.67	79.53		
10	100.00	90.00	61.22	76.8
	96.67	79.53		
	60.71	51.18		
	96.67	79.53		
	20.69	27.06		
	41.38	40.05		
14	66.67	54.76	56.12	68.9
	55.56	48.22		
	58.62	49.95		
	90.00	71.56		
15	100.00	90.00	65.34	82.6
	82.76	65.50		
	57.69	49.43		
	100.00	90.00		
	48.15	43.97		
	64.00	53.13		
16	82.14	64.97	56.51	69.5
	67.86	55.49		
	57.14	49.08		

[1] Average arcsine retransformed to percentage escapement.

Table 3.—Escapement of undersize king crab from standard pots (data from 1974 and 1975 experiments combined).

Number of days soaked	Percent escapement per pot	Arcsine percent escapement	Average arcsine	Average percent escapement[1]
1	10.34	18.72	32.62	29.1
	62.07	52.00		
	20.83	27.13		
2	50.00	45.00	45.97	51.7
	33.37	35.24		
	71.43	57.67		
3	70.34	57.04	54.34	66.0
	61.54	51.65		
4	71.43	57.67	53.39	64.4
	66.67	54.76		
	53.57	47.06		
	69.23	56.29		
	60.71	51.18		
6	85.71	67.78	64.06	80.9
	48.15	43.97		
	96.67	79.53		
	82.14	64.97		
7	77.78	61.89	61.05	76.6
	75.00	60.00		
	76.92	61.27		
8	96.67	79.53	71.30	89.7
	70.00	56.79		
	73.33	58.89		
	100.00	90.00		
10	100.00	90.00	71.08	89.5
	100.00	90.00		
	75.86	60.60		
	96.55	79.37		
	40.74	39.64		
	84.62	66.89		
14	92.86	74.55	72.23	90.7
	68.97	56.17		
	86.21	68.19		
	100.00	90.00		
15	100.00	90.00	76.24	94.4
	93.10	74.77		
	82.76	65.50		
	100.00	90.00		
	89.66	71.28		
	83.33	65.88		
16	96.67	79.53	69.98	88.3
	83.33	65.88		
	81.48	64.52		

[1] Average arcsine retransformed to percentage escapement.

regression technique described by Stevens (1951), a curve of the form $y = A + BR^x$ was fitted[5] to the data. In this model, y is the average arcsine and x is the duration of time in days. The asymptote (A) of the curve, when retransformed to the original scale, is the estimated value to which the cumulative percentage escapement tends. Estimated values (in the arcsine scale) of the parameters follow:

	Parameters			*Standard deviation*
Size	B	R	A	*of* A
Legal-size crab (120-139 mm)	−42.098	0.8421	63.715	5.451
Undersize crab (150-169 mm)	−51.711	0.7604	73.758	2.278

Using these values and retransforming to the original scale, we estimated the cumulative percentage escapement with time (Fig. 3). Also shown in Figure 3 are observed data points and a 95% confidence interval for the asymptote. For legal-size crab, the estimated asymptote was 80.4% with lower and upper 95% confidence limits of 63.5% and 93.0%. For undersize crab the estimated value was 92.2%, with lower and upper confidence limits of 87.4% and 95.9%.

Effect of Bait or Dead Crab

Bait in the form of chopped herring or dead crab d not "hold" tagged king crab in the test pots. Crab l baited pots more rapidly than unbaited pots (Fig. 4). The occurrence of new untagged king crab at time of retriev in the test pots baited with herring was many tim greater than pots containing dead crab or no bait (Fig. After 7 days, the new entries in herring-baited pots approached the rates for the unbaited and dead-cra baited pots, indicating that the herring became le effective as bait with time. Dead crab in test pots did no attract live king crab to the pots.

Mortality in Pots

Crab remains found in each pot were examined for ta numbers or scars. No unmarked crab were found dead. is unlikely that any dead crab were unaccounted for the carapaces remained intact even during a 15-day soak, and the pot mesh-size was small enough to prevent she from falling out during the lift. Mortality did not crease with time of soak (Table 4). However, the 15-d soak was a relatively short period to observe mortality caused by confinement. Natural mortality, tagging jury, and handling probably all contributed to t

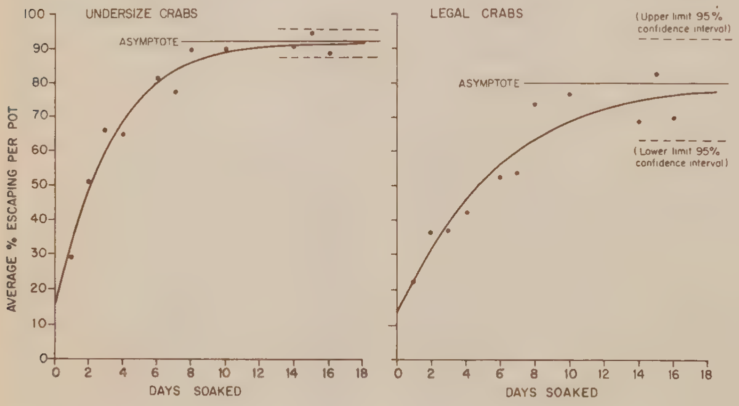

Figure 3.—Average escapement retransformed percent for small and large king crab from standard pots (data from 1974 and 1975).

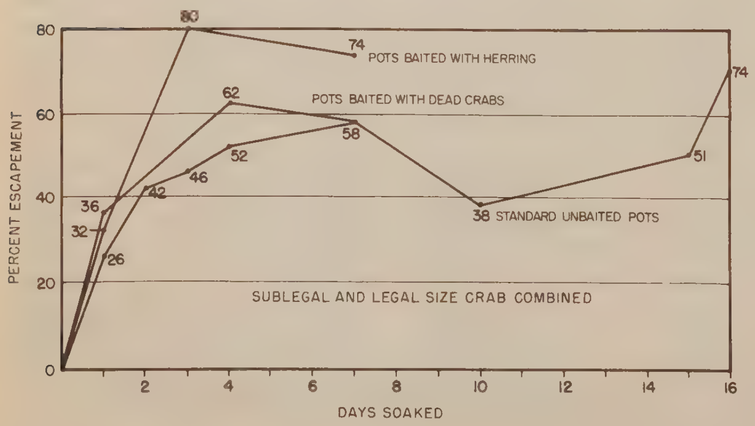

Figure 4.—King crab escapement from baited and unbaited pots after various soak intervals.

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[5]The asymptotic regression analysis was completed using a computer program written by George Hirschhorn of the Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, Seattle, WA 98112.

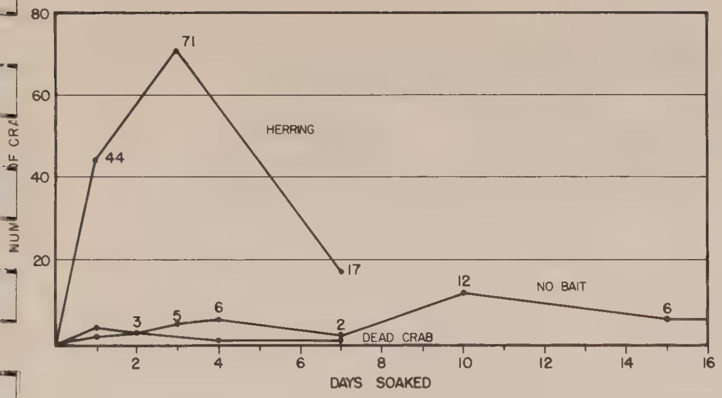

Figure 5.—Entry of new king crab (large and small combined) into pots containing herring, dead crab, or no bait.

observed mortality. As noted above, injuries did occur when crab-laden pots were pushed across the ship's rail d over the side. Some legs protruding through bottom shes were damaged, particularly in the experiment where 150 crab were crowded in each pot. We believe this may have contributed to the mortality observed for both al-size and undersize crab in that experiment. How- r, mortalities occurred to both injured and apparently uninjured crab.

ag Returns

Returns of tagged crab escaping pots were greater in 75 (30.0%) than during 1974 (16.0%) even though fishing effort was somewhat less in 1975 (Tables 5, 6). Moreover, we used a two-color, highly visible tag during 1975, ich was more likely to attract attention of fishermen or cessors than the single-color (dull orange) tag used in 1974.

Recovery of escaped undersize tagged crab was less in experiments than for legal-size crab. However, there no evidence that higher tagging loss caused this. On several occasions, fishermen reported seeing a tag on an undersize crab as it was being released into the water but late to retrieve it. Small crab taken upside down from pots by commercial fishermen were not turned over before release. Thus carapace tags may have been over- ked. Six of the 10 vessels returning most of the 1975 s were among the top 10 vessels returning tags in 1974. hese vessel crews were especially alert to the presence of tags on both undersize and legal-size crab.

Viability of Escaped Crab

If confinement in pots contributed to crab mortality, her in the pots or after escapement, we would expect mortality to be positively correlated with length of soak. No such correlation was observed to the end of confine- nt, but subsequent recovery of tagged crab indicated e correlation. The viability of crab that escaped the pots was tested by comparing recoveries of tagged crab from various experiments using pots with those free- eased. The latter crab were promptly tagged and released except for the initial group in 1974, which was held for under 2 days in the live tank. All were released in the area where experimental pots were soaking. As a result, free-release crab were distributed at intervals throughout the escape period of crab emerging from soaking pots.

Statistical tests, based upon the "G" statistic (Sokal and Rohlf 1969), showed no significant difference (30% level) in percentage recovered among 1975 free-releases and 1-4 day confinement for both undersize and legal-size crab. However, percentage recovered for both undersize (2 returned from 86 released) and legal-size (21 returned from 120 released) crab, 2.3% and 17.5%, respectively, confined for 10-16 days was significantly ($P < 0.05$) smaller than for the free-release groups (34.9% undersize and 35.2% legal size) and those confined for 1-4 days (31.4% and 33.1%). Furthermore, the recovery percentage for undersize crab confined 10-16 days was significantly less ($P < 0.05$) than that for legal-size crab confined for the same length of time. Only 1975 data were compared in this analysis to reduce effect of less visible tags used during 1974.

Incidental Catches

Those commercial fishermen interviewed agreed that the occurrence of other fish and invertebrate species in crab pots varied widely by fishing location and time of year. At times, fishermen using small-mesh web on their pots captured one or more Pacific cod in each pot lifted; Pacific halibut were taken less often. However, the fishermen reported that under some conditions halibut were present in up to 9% of their commercial pots lifted. All fish, except for viable halibut, were used for crab bait.

We captured both Pacific halibut and Pacific cod in Chiniak Bay. The remains of eight halibut, ranging in length from 84 cm to 123 cm, and six cod, from about 60 cm to 70 cm, were taken from 121 lifts during 1975. Soak time averaged 2 days. Occurrence was 6.6% for halibut and 5.0% for cod. All cod were viable, whereas only one halibut was alive. Six halibut were captured during the 1974 tests. Fishing effort, although not recorded, was considerably less than in 1975.

Table 4.—Observed mortality in pots at retrieval for tagged king crab confined in pots of various designs or configurations; except where noted, pots were unbaited.

		Undersize			Legal size		
Pot style tested	Days soak	No. tagged	No. found dead	% of tagged	No. tagged	No. found dead	% of tagged
Standard (1974)	4	88	2	2.3	90	1	1.1
	6	117	4	3.4	119	10	8.4
	8	120	0	0.0	119	6	5.0
	10	120	3	2.5	120	3	2.5
	14	120	4	3.3	119	3	2.5
	15	120	3	2.5	120	6	5.0
		685	16	2.3	687	29	4.2
Standard (1975)	1	85	3	3.5	90	2	2.2
	2	90	9	10.0	90	5	5.6
	3	60	7	11.7	60	3	5.0
	4	60	6	10.0	60	1	1.7
	7	90	9	10.0	90	13	14.4
	10	90	8	8.9	90	4	4.4
	15	77	2	2.6	88	11	12.5
	16	90	3	3.3	89	5	5.6
		642	47	7.3	657	44	6.7
Standard (crowded)	7	225	23	10.2	225	21	9.3
	9	225	21	9.3	225	24	10.7
		450	44	9.8	450	45	10.0
Standard (with bait)	1	60	1	1.7	60	0	0.0
	3	30	2	6.7	30	2	6.7
	7	60	4	6.7	59	5	8.5
		150	7	4.7	149	7	4.7
Nesting snow crab	4	60	2	3.3	60	2	3.3
	8	45	3	6.7	45	5	11.1
	10	60	4	6.7	60	5	8.3
		165	9	5.4	165	12	7.3
Nesting fiberglass pyramid	1	60	2	3.3	60	4	6.7
	2	60	2	3.3	60	14	23.3
	3	60	10	16.7	60	11	18.3
	4	60	1	1.7	60	8	13.3
	10	59	9	15.3	60	6	10.0
	16	60	0	0.0	60	1	1.7
		359	24	6.7	360	44	12.2
Nesting radical pyramid	1	60	0	0.0	60	0	0.0
	2	56	2	3.6	60	1	1.7
	3	30	4	13.3	30	1	3.3
	4	60	1	1.7	60	2	3.3
	10	invalid					
	16	60	4	6.7	60	7	11.7
		266	11	4.1	270	11	4.1
Standard (with planted dead crab)	1	60	3	5.0	60	3	5.0
	4	60	1	1.7	60	2	3.3
	7	60	9	15.0	60	4	6.7
		180	13	7.2	180	9	5.0

SUMMARY AND CONCLUSIONS

Analysis of the data indicates that an average of 92% of large undersize king crab and 80% of small legal-size king crab would escape from standard pots. Interpreted conversely, these data indicate retention of an average of 8% of undersize and 20% of legal-size crab.

With respect to crab confined in pots, experiments show that the presence of herring bait or dead crab did not reduce the escape of crab from the pots. Crab that escaped after 1-4 days were shown by tag recoveries not to have suffered additional postescape mortality as a resu of short-term confinement. On the other hand, 10-16 d confinement resulted in reduced recovery. Any procedure which would permit rapid escape of king crab from the pots would, therefore, introduce healthier viable cr back into the commercial stocks.

Although we did not make a detailed analysis of capture of species other than king crab, commercially usef fishes were found in the pots. These included t valuable Pacific halibut.

We must emphasize that we do not know how many

Table 5.—Combined return of tags from undersize and legal-size king crab that escaped from each 1974 experiment during various soak intervals.

Days soaked	Free release No. released	Free release Returned No.	Free release Returned %	Standard pot no bait No. escaped	Standard pot no bait Returned No.	Standard pot no bait Returned %	Jammed standard pots No. escaped	Jammed standard pots Returned No.	Jammed standard pots Returned %	Snow crab pot No. escaped	Snow crab pot Returned No.	Snow crab pot Returned %
0	694	170	24	—	—	—	—	—	—	—	—	—
4	—	—	—	87	14	16	—	—	—	43	6	14
6	—	—	—	145	20	14	—	—	—	—	—	—
7	—	—	—	—	—	—	368	57	15	—	—	—
8	—	—	—	183	35	19	—	—	—	31	4	13
9	—	—	—	—	—	—	370	63	17			
10	—	—	—	213	37	17	—	—	—	70	20	29
14	—	—	—	180	21	12						
15	—	—	—	208	27	13	—	—	—	—	—	—
		Total		1,016	154	15.2	738	120	16.3	144	30	20.8

Table 6.—Combined return of tags from undersize and legal-size king crab that escaped from each 1975 experiment during various soak intervals.

				Standard pots									Pyramid pots					
	Free release			No bait			Herring baited pot			Baited pot (dead crab)			Radical design			Typical design		
Days soaked	No. released	No. returned	%	No. escaped	No. returned	%	No. escaped	No. returned	%	No. escaped	No. returned	%	No. escaped	No. returned	%	No. escaped	No. returned	%
0	365	128	35	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1	—	—	—	49	12	24	37	11	30	43	11	26	87	35	40	20	12	60
2	—	—	—	75	25	33	—	—	—	—	—	—	50	20	40	36	7	19
3	—	—	—	56	14	25	48	16	33	—	—	—	38	16	42	36	9	25
4	—	—	—	64	15	23	—	—	—	75	26	35	48	18	38	48	14	29
7	—	—	—	103	30	29	88	34	39	70	20	29	—	—	—	—	—	—
10	—	—	—	67	20	30	—	—	—	—	—	—	—	—	—	39	10	26
15	—	—	—	57	22	39	—	—	—	—	—	—	—	—	—	—	—	—
16	—	—	—	134	28	21	—	—	—	—	—	—	80	23	29	58	14	24
			Total	605	166		173	61		188	57		303	112		237	66	
			Average			27.4			35.3			30.3			37.0			27.8

crab enter derelict pots and, until this is determined, the impact of lost pots upon the Alaska king crab population is uncertain.

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Guy Powell, and Rod Kaiser, Alaska Department of and Game, Kodiak, were instrumental in the suc- of these experiments by reviewing experimental plans. Powell supervised the recovery of our crab tags. Ra Spagnola, master of the chartered crab vessel *Tam-* and his crew contributed substantially to the field operations. Robert Loghry and Craig Forrest, Biological Technicians with the National Marine Fisheries Service, A Bay, Alaska, participated in all of the field studies. Cerda, visiting scientist from the University of Valparaiso, Chile, participated during 1975.

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History of the Fishery and Summary Statistics of the Sockeye Salmon, *Oncorhynchus nerka,* Runs to the Chignik Lakes, Alaska, 1888-1966

Michael L. Dahlberg

August 1979

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History of the Fishery and Summary Statistics of the Sockeye Salmon, *Oncorhynchus nerka,* Runs to the Chignik Lakes, Alaska, 1888-1966

MICHAEL L. DAHLBERG[1]

ABSTRACT

Annual runs of sockeye salmon to the Chignik Lakes, Alaska, decreased from an average of 1.9 million during the period 1922-39 to an average of 0.9 million during the period 1949-66. In order to study the dynamics of the runs' historic catch, escapement and age structure data were compiled by spawning stock and brood year. The history of fishing and management of the runs from inception of the fishery until 1966 is described. The high seas and coastal distributions of Chignik sockeye salmon indicated significant interception by the fishery in only one area other than the Chignik Bay and Chignik Lagoon; the fishery at Cape Igvak started in the mid-1960's. Results of the study were used to construct parent-progeny relationships that formed the basis for a management strategy to restore the runs to their former level of abundance.

INTRODUCTION

One approach to restoring sockeye salmon stocks[2] to their former levels of abundance is to precisely regulate harvest of each major race (Royce 1964). According to Royce (1960), such a course requires that the management agency 1) can define and recognize each major race[3] of salmon, 2) has accurate statistics on catch and apement, 3) can forecast the returns[4] accurately, 4) knows the number of spawners needed for maintenance, and 5) is aware of the gear and time needed to harvest the ired number of salmon. The management agency does have all this knowledge for any race of salmon in Alaska, but information has become available on the stocks of one sockeye salmon-producing system of west- Alaska, the Chignik River system, from which it can mulate a management strategy based on precise regulation of the harvest.

In this paper, historic catch and escapement statistics presented for each of the two major stocks of sockeye salmon in the Chignik River system. Current statistics have been routinely published and are later cited.

keye Salmon Research at Chignik, Alaska

The potential of the Chignik watershed for controlled dies of the life history of sockeye salmon was recognized early in the development of salmon research in Alaska (Gilbert and O'Malley 1921). Parallel studies of the life history of sockeye salmon were started by the U.S. Bureau of Fisheries at Karluk in 1921 and at Chignik in 1922 with the main purpose of ascertaining "what relation exists between spawning colonies of varying size and the number of progeny that they furnish" (Gilbert 1929). The Karluk and Chignik Rivers were selected because it was believed the fishery operated solely on fish bound for these particular watersheds.

In 1928 the complexities of the life cycle and dynamics of the sockeye salmon populations of Chignik were brought to light, and intensive study of the freshwater life history of the Chignik sockeye salmon began (Higgins 1930). Considerable progress was made in determining the pattern of the life history of Chignik sockeye salmon and the relationship between the numbers of spawners and returning progeny (Holmes 1934). However, in 1934 research was drastically reduced because of budget restrictions, and the only activity was collection of scales for later study (Higgins 1936). A fish-counting weir was first erected in Chignik River in 1922 to estimate the escapement. The counting weir was not maintained in 1938, from 1940 through 1948, and in 1951. Each year since 1952 a weir has been in operation to count the escapement; because of turbid water and lack of adequate sites, counting towers used in the Bristol Bay district are not feasible at Chignik.

Tagging studies were conducted at Chignik by the Fisheries Research Institute (FRI), University of Washington, in 1949 and 1952, and a research program funded by the Chignik salmon canning industry began in 1955. From 1955 to 1960 the research program consisted of studies of the age composition of the runs, annual enumeration of smolts, and an investigation of predation on juvenile salmon by Dolly Varden, *Salvelinus malma,* and coho salmon, *Oncorhynchus kisutch*, (Roos[5, 6, 7], 1959, 1960). Beginning in 1961 the FRI intensified ecological studies of the nursery lakes. Results of those studies have been reported by Narver (1966), Phinney (1970), Parr (1972), and Burgner and Marshall[8]. Dahlberg (1973) analyzed the historical records of the fishery and reported on the dynamics of the sockeye salmon returns to Chignik from the inception of the fishery through 1966. Although all five species of Pacific salmon found in North America occur at Chignik, sockeye salmon are the most abundant and commercially important species. This report treats only sockeye salmon at Chignik. Narver (1966) and Parr (1972) described the life histories of fishes associated with sockeye salmon in the Chignik lakes.

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[1]Northwest and Alaska Fisheries Center Auke Bay Laboratory, National Marine Fisheries Service, NOAA, P.O. Box 155, Auke Bay, AK

ock refers to each aggregation that can be managed separately (Ricker 1966); run, as defined by Mathews (1966), signifies the total number of mature sockeye salmon entering the watershed in 1 yr (catch plus escapement).

ce, the same as stock; see above.

turns refers to the total number of mature progeny produced by one spawning, regardless of the time of return.

The Watershed

The Chignik watershed is located on the Alaska Peninsula approximately halfway between the tip of the Alaska Peninsula and Kodiak Island (Fig. 1). Black and Chignik Lakes drain into the Pacific Ocean and form a natural northwest-southeast pass through the Aleutian Mountain Range. The watershed covers an area of approximately 1,520 km² including two lakes of 63.8 km² total surface area. Atwood (1911) and Knappen (1929) discussed in detail the geology of the region and briefl described the geography and vegetation; Murie (19 detailed the fauna of the Alaska Peninsula.

Because the lakes are important as rearing areas for venile sockeye salmon, they have been closely studied; complete description of the two lakes is presented Narver (1966). Black Lake is shallow (44% of the are <2 m deep), warms rapidly in the spring, and is usua turbid (typical Secchi disk reading is <1 m) throughou the summer. Chignik Lake, although smaller in than Black Lake, is six times greater in volume and erally clearer. Although the lakes are different physicall (Table 1), together they show a marked contrast in bio logical activity when compared with 24 other sock salmon-producing lakes in western Alaska (Burgner e 1969). The Chignik system ranked second in number o spawners per unit of lake surface area, first in rat photosynthetic activity (area and volume), first in tent of chlorophyl *a* per unit of lake volume, and sec in content of total dissolved solids, and generally showe high concentrations of trace elements. Black Lake Chignik Lake had the highest standing crops of ph plankton among the lakes compared.

The lakes are connected by Black River (12 km long which flows south along the edge of the Aleutian M tain Range. Two major spawning tributaries enter B River. West Fork, entering from the west, drains th northeast slope of Mount Veniaminoff (Fig. 1), a volcan which erupted as recently as 1956 (Roos see footnot Chiaktuak Creek enters from the east and drains a v parallel to Chignik Lake. Bearskin Creek also enter Black River but is of minor importance as a spaw stream; small numbers of spawners are found occasi ly in the upper reaches (Phinney 1970).

The lower lake is drained by Chignik River (7.2 k long), which is normally influenced by tidal actio nearly one-half its length. The highest spring tides the river up to the lake outlet.

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[5] Roos, J. F. 1959. Report on Chignik adult red salmon studies, 1958. Unpubl. manuscr., 12 p. Fish. Res. Inst., Univ. Washington, Seattle.

[6] Roos, J. F. 1959. Red salmon tagging at Chignik, Alaska during 1959. Unpubl. manuscr., 9 p. Fish. Res. Inst., Univ. Washington, Seattle.

[7] Roos, J. F. 1960. Life history of red salmon, *Oncorhynchus nerka* (Walbaum), at Chignik, Alaska. Unpubl. manuscr., 56 p. Fish. Res. Inst., Univ. Washington, Seattle.

[8] Burgner, R. L., and S. L. Marshall. 1974. Optimum escapement studies of Chignik sockeye salmon. Anadromous Fish Project Final Report for period ending June 30, 1973. Report No. FRI-UW-7401. Fish. Res. Inst., Univ. Washington, Seattle, 91 p.

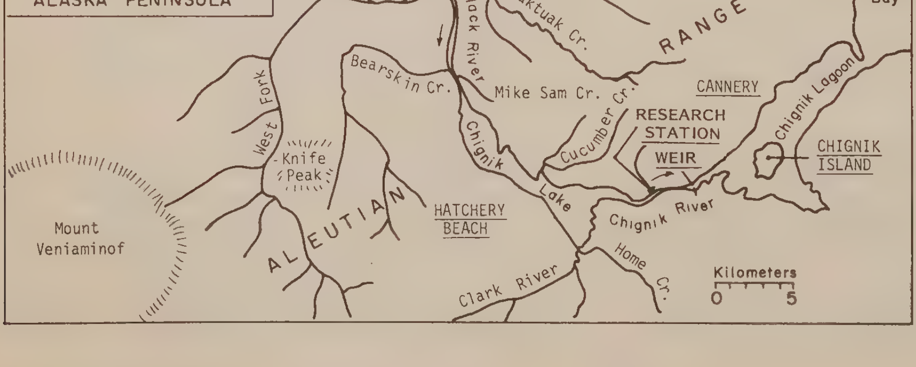
Ancnorage
Bristol Bay
Kodiak Island
North Pacific Ocean
Chignik
ALASKA PENINSULA
Crater Cr.
RESEARCH STATION
Milk Cr.
Cathedral Cr.
Broad Cr.
Big Spring
N
Black Lake
Alec River
Conglomerate Cr.
Rifle Cr.
RESEARCH STATION
Fan Cr.
Chiaktuak Cr.
Black River
RANGE
Chignik Bay
Bearskin Cr.
Mike Sam Cr.
Cr.
CANNERY
Chignik Lagoon
West Fork
Cucumber
RESEARCH STATION
WEIR
CHIGNIK ISLAND
Knife Peak
Chignik Lake
Chignik River
Mount Veniaminof
ALEUTIAN
HATCHERY BEACH
Home Cr.
Clark River
Kilometers
0
5

Figure 1.—Map of the C River watershed with in western Alaska.

Table 1.—Morphometric measurements of Chignik and Black Lakes and Chignik Lagoon (from Dahlberg 1973).

Source	Altitude (m)	Depth (m) Mean	Depth (m) Maximum	Water area (km²)	Volume (km³)	Shoreline Length (km)	Shoreline Development	Flow at outlet (m³/s)	Flow at outlet Date
Black Lake	15	3	6	41.1	0.10	27.0	1.19	17.0	25 June 1963
Chignik Lake	5	29	64	22.7	0.64	27.7	1.64	79.5	23 June 1963
	—	—	—	—	—	—	—	35.8	13 Aug. 1963
Total	—	—	—	63.8	0.74	—	—	—	—
Chignik Lagoon	—	3	15	41.8	0.13	46.7	2.04	—	—

Chignik Lagoon (12 km long) is a nearly enclosed estuary having a sandy or muddy, flat bottom with scattered ches of algae and extensive areas of eel grass stera). Water covers about 42 km² at high tide, and about half that at low tide. Low and high tide salinities range from 10 to 17‰ in the upper lagoon and from 30 32‰ at the sand spit near the outlet. The importance the estuary as a secondary rearing area for juvenile sockeye salmon has been investigated by Phinney (1968); ge catches of postsmolt sockeye salmon have been en by beach seine and surface trawl in the lagoon during June and July (Narver and Dahlberg 1965; Phinney 1968).

e Climate

The climate of the region is strongly maritime because Alaska Peninsula is a comparatively small body of d between two large water masses, the North Pacific Ocean and the Bering Sea. The weather conditions reted by Atwood (1911) and Knappen (1929) remain ical. The summers are short and cool; although there may be many days of wet weather, the rainfall is seldom excessive. A great many overcast days occur. Violent ds often exceeding 161 km/h (100 mph) have been orded. Winter temperatures are more moderate than those in Bristol Bay; recording thermometers left in cabins over the winters of 1961-67 showed a low of −27°C 17°F). Ice breakup on the lakes occurs in April or y, much earlier than in the lakes of the Bristol Bay district. Long-term weather records are not available for the immediate area; Kodiak Island (270 km to the northt) is the nearest location with extensive weather ords, although some data are available from nearby Port Heiden on the north side of the peninsula.

tory of the Commercial Fishery

Cannery operations.—Commercial exploitation of gnik sockeye salmon began in 1888 when the Fisher's Packing Company of Astoria, Oreg., sent a crew to Chignik Bay to prospect for fish; they returned in the fall with 2,160 barrels of salted salmon. In 1889 canning ations were started in plants of the Fishermen's king Company, Chignik Bay Company of San Francisco, and the Shumagin Packing Company from land, Oreg. (Moser 1899). Operating agreements been the companies proved so successful in 1890 and 1891 that they joined the pool of canneries of the Alaska Packing Association in 1892. In 1893 they all became members of the Alaska Packers Association, and only one cannery was operated as a result of increased operation efficiency (Moser 1899).

The ease with which fish were captured at Chignik attracted more investment into the fishery; in 1896 Hume Brothers and Hume, and the Pacific Steam Whaling Company each built a cannery (Cobb 1930). In 1901 these companies became part of the Pacific Packing and Navigation Company, which in turn became part of the Northwestern Fisheries Company in 1905. In 1910 the Columbia River Packers Association built yet another cannery in the area. Competition was intense until 1914 when the three companies then operating—Alaska Packers Association (APA), Columbia River Packers Association (CRPA), and Northwestern Fisheries Company (NFC)—agreed to an equal division of the catch (Rich and Ball 1930).

Industry relationships remained static until 1926 when H. W. Crosby operated a floating salmon cannery, Salmon King, for one season. In 1932 Crosby returned and built a land-based cannery; the same year, CRPA, NFC, and APA made a combined pack at the APA cannery. The following season, 1933, Pacific American Fisheries (PAF) acquired the Northwestern Fisheries Company, and the PAF, APA, and CRPA combined canning operations. The APA acquired the Chignik interests of PAF and CRPA during the ensuing years and continues to operate their cannery at Chignik (Pacific Fisherman Yearbook 1915-67; National Fisherman Yearbook 1968, 1969; Pacific Packers Report 1970-76).

Crosby changed the name of his operation to Chignik Lagoon Packing Company in 1936, and after two other changes gave it the name Chignik Fisheries Company in 1947. Beginning in 1953, APA and Chignik Fisheries Company entered into an agreement to can all fish in the APA cannery; the cannery of the Chignik Fisheries Company serves as a base of supply and operations for its fishing fleet (Roos see footnote 7). In 1968, Columbia-Wards Company purchased the Chignik Fisheries cannery and has continued operations under the same arrangements with the APA (Pacific Packers Report 1976).

Fishing gear.—Pile traps (Scudder 1970) were the principal fishing gear, and beach seines took a small part of the catch before 1900. The water at Chignik was too clear and the channel too narrow for effective gillnetting (Moser 1899). The number of units of gear operated in

Table 2.—Recapitulation of types of fishing gear and catches of sockeye salmon by gear (percentage), fishing seasons, fishing regulations, and numbers of days fished at Chignik, 1895-1966 (Dahlberg 1968).

	Number of units of gear			Catch by gear (percentage)						
Year	Traps	Seines[1]	Gill nets	Traps	Seines	Gill nets	Fishing[2] season	Fishing[3] regulations	Number of days fished	Source
1895	Na[4]	Na	Na	Na	Na	Na	10 June- 2 Aug.	1	45	Moser (1899)
1896	17	10	13	Na	Na	Na	15 June-14 Aug.	1	51	Moser (1899)
1897	23	10	10	Na	Na	Na	7 June-27 Aug.	1	68	Moser (1899)
1898	23	Na	Na	Na	Na	Na	9 June- 8 Aug.	1	50	Moser (1899)
1899	Na	Na	Na	Na	Na	Na	9 June-22 Aug.	1	61	Moser (1902)
1900	24	8	26	70.0	5.0	20.0	11 June-12 Aug.	1	52	Moser (1902)
1901	21	Na	Na	Na	Na	Na	13 June-24 Aug.	1	60	Rich and Ball (1930)
1902	21	Na	Na	Na	Na	Na	9 June-10 Aug.	1	52	Rich and Ball (1930)
1903	29	Na	Na	Na	Na	Na	8 June-23 Aug.	1	63	Rich and Ball (1930)
1904	28	Na	Na	Na	Na	Na	10 June- 9 Aug.	1	50	Rich and Ball (1930)
1905	12	Na	Na	Na	Na	Na	4 June-13 Aug.	1	57	Rich and Ball (1930)
1906	7	Na	Na	Na	Na	Na	11 June-12 Aug.	1	52	Rich and Ball (1930)
1907	8	Na	Na	Na	Na	Na	10 June-12 Aug.	2	50	Rich and Ball (1930)
1908	8	Na	Na	Na	Na	Na	6 June- 8 Aug.	2	44	Rich and Ball (1930)
1909	8	Na	Na	Na	Na	Na	14 June-15 Aug.	2	50	Rich and Ball (1930)
1910	18	Na	Na	Na	Na	Na	16 June-31 Aug.	2	50	Rich and Ball (1930)
1911	29	Na	Na	Na	Na	Na	15 June- 5 Sept.	2	64	Rich and Ball (1930)
1912	37	Na	Na	Na	Na	Na	10 June- 3 Sept.	2	68	Rich and Ball (1930)
1913	37	Na	Na	Na	Na	Na	9 June-24 Aug.	2	60	Rich and Ball (1930)
1914	9	Na	Na	Na	Na	Na	9 June-27 Aug.	2	64	Rich and Ball (1930)
1915	9	Na	Na	Na	Na	Na	10 June-23 Aug.	2	58	Rich and Ball (1930)
1916	9	Na	Na	Na	Na	Na	12 June- 9 Sept.	2	70	Rich and Ball (1930)
1917	12	Na	Na	Na	Na	Na	10 June-14 Sept.	2	78	Rich and Ball (1930)
1918	12	Na	Na	Na	Na	Na	12 June- 4 Sept.	2	67	Rich and Ball (1930)
1919	14	Na	Na	Na	Na	Na	17 June-17 Sept.	2	74	Rich and Ball (1930)
1920	12	Na	Na	Na	Na	Na	16 June-14 Sept.	2	72	Rich and Ball (1930)
1921	9	Na	Na	Na	Na	Na	17 June-29 Aug.	2	58	Rich and Ball (1930)
1922	9	Na	Na	Na	Na	Na	16 June-27 Aug.	2	55	Rich and Ball (1930)
1923	9	Na	Na	Na	Na	Na	15 June-22 Aug.	2	52	Rich and Ball (1930)
1924	9	Na	Na	Na	Na	Na	20 June-16 Sept.	2,5	52	Rich and Ball (1930)
1925	9	Na	Na	Na	Na	Na	19 June-11 Sept.	2,5	46	Rich and Ball (1930)
1926	10	Na	Na	Na	Na	Na	15 June- 3 July	2,5	16	Rich and Ball (1930)
1927	10	Na	Na	Na	Na	Na	16 June-15 Sept.	2	72	Rich and Ball (1930)
1928	11	Na	Na	Na	Na	Na	12 July -23 Sept.	2,5	58	Rich and Ball (1930)
1929	10	Na	Na	Na	Na	Na	13 June-22 Sept.	2	87	Rich and Ball (1930)
1930	6	Na	Na	Na	Na	Na	4 July -11 Aug.	2,5	26	Mgt. Biol. Annu. Rep.
1931	8	Na	Na	Na	Na	Na	4 June-16 Sept.	2,5	78	Mgt. Biol. Annu. Rep.
1932	8	1	5	99.4	0.5	0.1	8 June-17 Sept.	2	81	Mgt. Biol. Annu. Rep.
1933	8	22	4	97.0	2.8	0.2	12 June-19 Aug.	2	54	Mgt. Biol. Annu. Rep.
1934	7	Na	Na	89.5	9.7	0.8	3 June-12 Sept.	2	81	Mgt. Biol. Annu. Rep.
1935	7	Na	Na	78.5	20.6	0.9	4 June-12 Sept.	2,5	80	Mgt. Biol. Annu. Rep.
1936	8	21	4	74.4	23.7	1.9	1 June-10 Sept.	2,5	47	Mgt. Biol. Annu. Rep.
1937	8	Na	Na	Na	Na	Na	8 June- 4 Sept.	2,5	35	Mgt. Biol. Annu. Rep.
1938	4	Na	Na	54.3	43.0	2.7	22 June- 1 Sept.	2,5	68	Mgt. Biol. Annu. Rep.
1939	8	14	6	Na	Na	Na	5 June- 1 Sept.	2	70	Mgt. Biol. Annu. Rep.
1940	4	18	2	2.0	92.8	5.2	2 June- 9 Aug.	2	56	Mgt. Biol. Annu. Rep.
1941	8	23	5	68.2	29.9	1.9	4 June-30 Aug.	3	58	Mgt. Biol. Annu. Rep.
1942	4	18	5	63.2	34.1	2.7	8 June-29 Aug.	3	56	Mgt. Biol. Annu. Rep.
1943	4	15	2	70.3	28.0	1.7	5 June-23 Aug.	3	53	Mgt. Biol. Annu. Rep.
1944	4	21	2	59.0	38.9	2.1	5 June-18 Aug.	3	48	Mgt. Biol. Annu. Rep.
1945	5	17	5	66.4	29.8	3.8	8 June-11 Aug.	3	43	Mgt. Biol. Annu. Rep.
1946	7	22	7	49.0	50.0	1.0	3 June-20 Aug.	3	52	Mgt. Biol. Annu. Rep.
1947	8	58	3	37.2	62.3	0.5	1 June-29 Aug.	4,5	50	Mgt. Biol. Annu. Rep.
1948	7	70	3	34.6	64.8	0.6	1 June-21 July	4,5	28	Mgt. Biol. Annu. Rep.
1949	5	41	2	30.0	69.6	0.4	10 June-15 Sept.	4,10	28	Mgt. Biol. Annu. Rep.
1950	4	55	18	24.5	74.1	1.4	6 June-15 Sept.	4,10	38	Mgt. Biol. Annu. Rep.
1951	4	64	0	22.8	77.2	0	6 June-17 Aug.	4,10	24	Mgt. Biol. Annu. Rep.
1952	4	Na	0	28.4	67.9	3.7	16 June-26 June	4,10	8	Mgt. Biol. Annu. Rep.
1953	4	26	0	25.0	75.0	0	22 June-24 July	4,10	14	Mgt. Biol. Annu. Rep.
1954	4	63	1	24.1	75.8	0.1	22 June-26 June	4,10	5	Mgt. Biol. Annu. Rep.
1955	0	55	0	0	100.0	0	18 June-17 July	5,6	20	Mgt. Biol. Annu. Rep.
1956	0	42	0	0	100.0	0	20 June- 1 Sept.	5,6	20	Mgt. Biol. Annu. Rep.
1957	0	37	0	0	100.0	0	26 June-22 Aug.	5,7	40	Mgt. Biol. Annu. Rep.

Table 2.—Continued.

Year	Number of units of gear			Catch by gear (percentage)			Fishing[2] season	Fishing[3] regulations	Number of days fished	Source
	Traps	Seines[1]	Gill nets	Traps	Seines	Gill nets				
1958	0	40	0	0	100.0	0	18 June-22 Aug.	5,8	27	Mgt. Biol. Annu. Rep.
1959	0	29	0	0	100.0	0	17 June-18 Sept.	5,8	44	Mgt. Biol. Annu. Rep.
1960	0	17	0	0	100.0	0	5 June-11 Sept.	5,7	61	Mgt. Biol. Annu. Rep.
1961	0	33	0	0	100.0	0	8 June-27 Aug.	5,6	32	Mgt. Biol. Annu. Rep.
1962	0	25	0	0	100.0	0	20 June-19 Aug.	5,9	41	Mgt. Biol. Annu. Rep.
1963	0	22	0	0	100.0	0	3 July - 1 Sept.	9,10	56	Mgt. Biol. Annu. Rep.
1964	0	21	0	0	100.0	0	14 June-27 Aug.	9,10	69	Mgt. Biol. Annu. Rep.
1965	0	24	0	0	100.0	0	19 June-28 Aug.	9,10	42	Mgt. Biol. Annu. Rep.
1966	0	25	0	0	100.0	0	30 June- 7 Sept.	9,10	44	Mgt. Biol. Annu. Rep.

[1] For the period 1954-66 the number of seines is the weighted daily mean.

[2] Inclusive dates for beginning and end of entire fishing season.

[3] Fishing regulations coded: 1. Weekly closure of 30 h, 0000 Friday to 0600 Sunday. 2. Weekly closure of 36 h, 1800 Saturday to 0600 Monday. 3. Weekly closure of 60 h, 0600 Wednesday to 0600 Thursday; 1800 Saturday to 0600 Monday. 4. Weekly closure of 60 h, 1800 Friday to 0600 Monday. 5. Periodic closure by management biologist. 6. Weekly closure of 3 days. 7. Weekly closure of 2 days. 8. Weekly closure of 4 days. 9. Weekly closure (5 days or 4 days) changed during season by the management biologist. 10. Fishing periods changed by emergency regulations set by management biologist.

[4] Na = not available.

Chignik Lagoon and Chignik Bay, length of fishing seasons, and fishing regulations have varied consider- ly during 1895-1966 (Table 2; Fig. 2).

Because of the unique time of entry of the Black Lake and Chignik Lake stocks into Chignik Lagoon, to be shown later, the distribution of open and closed fishing riods within each season indicates to some extent ich stock was exploited (Fig. 3). In 1954, for example, there was only one short open period which resulted in a fourfold difference in rates of exploitation between cks. The lengthy season and the large number of traps concentrated in this small area (Chignik Lagoon is about 12 km long) indicate an intense fishery from 1900 to 1914. Moser (1902) visited Chignik in 1898 and again in 1900 d stated, "the lagoon and approaches and the river ap-

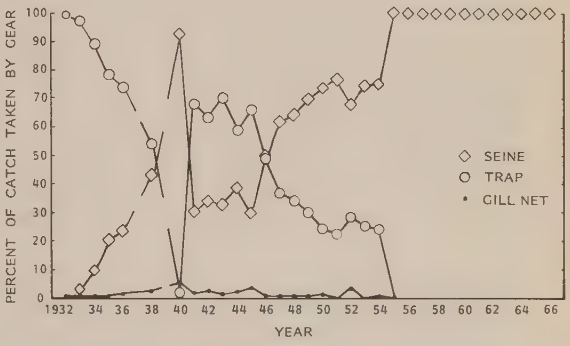

Figure 2.—Percentages of catches of sockeye salmon caught by trap, seine, and gill net in the Chignik fishery, 1932-66.

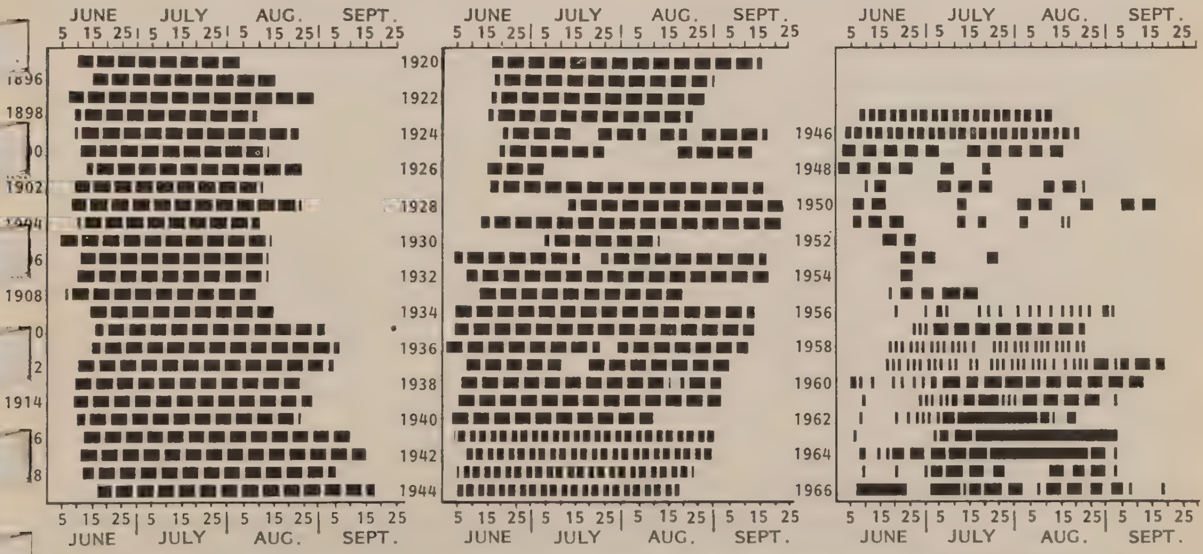

Figure 3.—Open and closed fishing periods for the Chignik fishery, 1895-1966; bars represent time periods open to fishing.

proaches are studded with traps, some with leads 3,500 feet long, and sometimes so interlaced that at a distance the channel appears completely blocked, and it hardly seems possible for a fish to pass." Dahlberg (1968) presented figures showing the location of traps fished in Chignik Lagoon during 1899 and 1902.

Because there is some question as to the effectiveness of the older types of gear, I calculated fishing effort from the data on gear (Table 2) and catch data. The unit of effort chosen was the trap-day, i.e., the number of traps fished, which yields the total trap days in season *i*. Total trap catch in season *i* divided by total trap days within season *i* yields catch per unit of effort.[9]

The fishing effort from 1905 to 1909 was low and the catch of sockeye salmon per unit of effort (CPUE) was exceedingly high (Fig. 4). The sharp drop in the CPUE and the concomitant rise in units of gear between 1909 and 1913 indicate "keen competition" between companies during this period (Rich and Ball 1930). The agreement in 1914 to equally divide the catch among the three companies brought about much more efficient conduct of the fishery; however, its intensity was to no extent reduced in later years (Rich and Ball 1930), e.g., in 1922 more than 75% of the run was harvested (Alaska Fishery and Fur-Seal Industries 1922).[10] While it appears from Figure 4 that the CPUE may have risen during the period 1950-65, this may be due to a change in the effi-

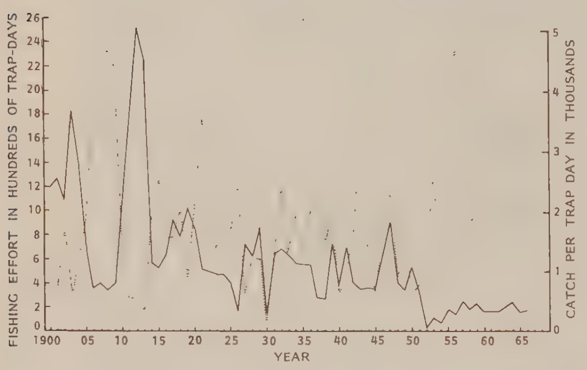

Figure 4.—Trends in fishing effort (solid line) and catch (dotted line) of sockeye salmon per unit of effort at Chignik, 1900-66.

ciency or catchability of the newer gear. With the in duction of powered seine blocks, synthetic fiber nets, an modern seine boats in recent years, one would ex greater efficiency per unit of gear.

Fishing regulations.—There was little, if an enforcement of fishery regulations in the Chignik fis before 1922. There were no statutory regulations pri 1895, only a weekly closure of 30 h for the period 189 1906, and one of 36 h for 1907-40 (Table 2). Cooley (196 pointed out that starting in 1892 the U.S. Fish Com sion had funds to support only one inspector and a sistant for the enforcement of fishing regulations in t entire territory of Alaska. They were forced to depend industry transportation to make their rounds durin 3-mo season.

A fish-counting weir was first established in Chign River in 1922 by the U.S. Bureau of Fisheries. The has not been installed every year since that time, b management agent has been on duty to check the fis area during closed periods. However, inspection of Fi ure 2 shows that until 1925 there had never been days of fishing during the season. In 1924, with the sage of the White Act,[11] which required 50% escapeme in streams where counting weirs were maintained, t fishery was subjected to periodic closures by the man ment agent. In 1925 it was required that the mini annual escapement at Chignik be set at 1 million fi (Rich and Ball 1930). This requirement was met near every year until 1938. Management of the Chi fishery was based mainly on the rule of 50% escape and 50% catch under the White Act until the time of i repeal in 1957.[12] In recent years target escapements mated from spawner-return relationships have been as management guidelines to secure adequate spaw densities (Dahlberg 1973).

Catch trend.—The general trend of catch decli not long after the inception of the fishery is typical many other salmon fisheries in Alaska (Fig. 5). Catch

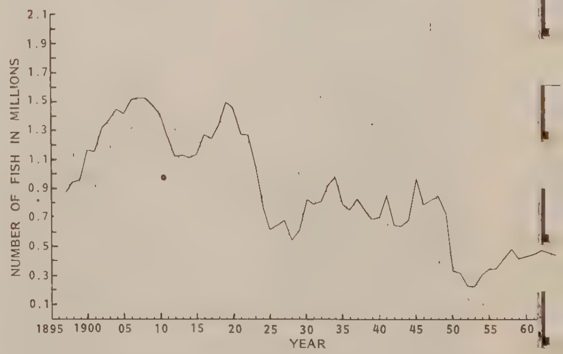

Figure 5.—Commercial catches of sockeye salmon at Chignik, 18 1966; unsmoothed curve (broken line) and curve smoothed moving average of 5 (solid line).

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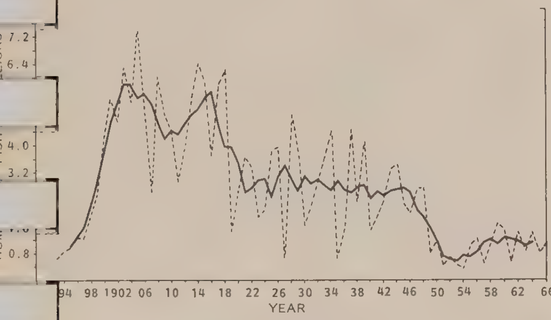
[9] Since beach seines gradually replaced traps over the years (Fig. 3, Table 2), I chose to convert the effort by gill nets and seines to trap effort in order to make all the fishing effort data comparable between years. I calculated relative fishing powers, by gear type, from the percentage of the catch of each type of gear and the number of units of each type of gear operating concurrently. I found that on the average, one trap was the equivalent of 5.9 beach seines or 26.2 gill nets. These figures are to be used with caution since the selectivity of trap sites and the efficiency of beach seines used during the period 1940 to 1954 and those used in the 1970's are probably not the same. However, these relative fishing powers can be used for gross comparisons of fishing effort.

[10] The data for 1917 to 1950 were taken from the publication series Alaska Fishery and Fur-Seal Industries. This series was published annually as appendices to the Report of Commission of Fisheries until 1940. Beginning in that year, they were published in the U.S. Fish and Wildlife Service's Statistical Digest Series.

[11] Public Law 204, 68th Congress, 1924 (Cooley 1963).

[12] Public Law 296, 85th Congress, 1957.

radually increased as the fishery developed, leveled off ntil the White Act took effect in 1924 at which time they ed, remained at an intermediate level for several 925-48), and then dropped sharply after 1949 to a w level. The catch data for the Nushagak district of ristol Bay (Mathisen 1971), show a unique similarity in Fig. 6) except for the timing of the fall from ini- h production. The decline of sockeye salmon pro- uction in the Nushagak district preceded that at hignik by a few years. It is noteworthy that these two ndent sockeye salmon systems exhibit the same istorical development and both show a decline in re- urn per spawner.



igure 6.—Commercial catches of sockeye salmon in the Nushagak strict, Bristol Bay, 1893-1966 (after Mathisen 1967); unsmoothed oken line) and curve smoothed by a moving average of 5 e).

CATCHES AND ESCAPEMENTS OF THE CHIGNIK SOCKEYE SALMON RUNS, 1888-1966

Catch and escapement, age and size composition, sex ming of the run, and distribution of the escape- n the spawning grounds are among the important equired statistics for setting management regulations r the establishment and maintenance of maximum sus- yield.

atches and Escapements

ement records began accumulating after of a weir in Chignik River in 1922. Catch statistics have been recorded from the beginning of the fishery in 1888; more detailed records have been kept since the Chignik canners joined the Alaska Packers Association in 1893 (Moser 1899). The long-term changes in abundance of Chignik sockeye salmon have been about twofold (Table 3).

Catch records.—Several sources of information were used to compile a complete record of the annual catches of Chignik sockeye salmon since 1888 (Moser 1899, 1902; Rich and Ball 1929, 1930; Alaska Fishery and Fur-Seal Industries 1917-50; Kasahara 1963; Pacific Fisherman Yearbook 1915-67; Pacific Salmon Inter-Agency Council 1966; Roos[13], see footnotes 5, 7; Calkins[14]). The two most valuable sources were 1) annual reports of the Chignik cannery superintendents, Alaska Packers Association, over the years 1895-1955; and 2) various reports of the management agents for the U.S. Bureau of Fisheries (1922-39), the U.S. Fish and Wildlife Service (1940-59), and the Alaska Department of Fish and Game (1960-66) (microfilms of these documents are on file in the archives of the FRI). I resolved inconsistencies in the reports compiled and issued by various agencies and individuals by cross-checking several sources; in the event of a major disagreement, I accepted the daily catch figures compiled by either the management agency or canning industry. Many arithmetical errors were discovered in the historical records; in these instances, I used the summation of the daily catch figures (Dahlberg[15]). Catch records were complete for all the years covered in this study (1888-1966).

Escapement records.—Daily weir counts were used to compile annual escapement records for those years in which a weir was operated in the Chignik River. The counting weir was not maintained in Chignik River during 1938, from 1940 through 1948, and in 1951. Moreover, in some years (1924, 1931, 1933) the weir was

Table 3.—Long-term changes in abundance of Chignik sockeye salmon (Dahlberg 1968).

	Chignik Lake				Black Lake				Total run			
	Catch 1,000's	Escape-ment 1,000's	Total 1,000's	Rate of exploi-tation[1]	Catch 1,000's	Escape-ment 1,000's	Total 1,000's	Rate of exploi-tation[1]	Catch 1,000's	Escape-ment 1,000's	Total 1,000's	Rate of exploi-tation[1]
Mean 1922-39	504	563	1,067	0.472	290	497	787	0.368	794	1,060	1,854	0.428
Mean 1949-66	240	326	566	0.423	145	201	346	0.419	385	527	912	0.422
Percent change[2]	−52.5	−42.1	−47.0	−10.4	−49.8	−59.5	−55.9	+13.9	−51.5	−50.2	−50.8	−3.8

[1] Rate of exploitation as defined by Ricker (1958:20).

[2] Expressed as a percentage of the mean for the period 1922-39.

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[13] Roos, J. F. 1957. Report on Chignik adult red salmon studies, 1955-1956. Unpubl. manuscr., 58 p. Fish. Res. Inst., Univ. Washington, Seattle.

[14] Calkins, T. P. 1958. Report on Chignik adult red salmon studies, 1957. Unpubl. manuscr., 59 p. Fish. Res. Inst., Univ. Washington, Seattle.

[15] Dahlberg, M. L. 1967. Chignik catch-escapement analysis. Fish. Res. Inst., Comput. Program FRD 295, Univ. Washington, Seattle, 4 p.

damaged by high water, and the escapement was inaccurately assessed. Because it was desirable to have a continuous record of past escapements, estimates were used for missing data (Table 4). The estimates for 1924, 1931, and 1933 were made by U.S. Bureau of Fisheries personnel stationed at Chignik in these years; the estimate for 1951 represents the total of weekly estimates of escapement made by the management agent, U.S. Fish and Wildlife Service, at Chignik in that year.

Table 4.—Estimated escapements of sockeye salmon at Chignik, Alaska, for those years in which weir counts either were not available or were unreliable (Dahlberg 1968).

Year	Escapement estimate	Description of run[1]	Time period	Source
1924	115,000	—	4 June - 5 July	U.S. Bur. Fish. personnel
1931	107,600	—	To 10 July	U.S. Bur. Fish. personnel
1933	426,000	—	After 25 June	U.S. Bur. Fish. personnel
1938	482,000	550,000	All year	FRI, Dahlberg
1940	329,000	1,100,000	All year	FRI, Dahlberg
1941	906,000	Very light	All year	FRI, Dahlberg
1942	960,000	Very light	All year	FRI, Dahlberg
1943	1,907,000	Excellent run	All year	FRI, Dahlberg
1944	643,000	Unusually poor	All year	FRI, Dahlberg
1945	369,000	Far below average	All year	FRI, Dahlberg
1946	1,514,000	Good escapement	All year	FRI, Dahlberg
1947	3,781,000	Best run in many years	All year	FRI, Dahlberg
1948	698,000	—	All year	FRI, Dahlberg
1951	616,000	—	All year	U.S. Fish and Wildlife Service personnel

[1] Source: Alaska Fishery and Fur-Seal Industries (1938, 1940-48).

Providing estimates of the escapement for 1938 and the period 1940-48 was more complex since daily or weekly estimates of the escapement were not available. In these cases, the ratio of escapement to catch was calculated from data obtained immediately before and after the period, and escapement in the period was estimated by taking the product of the catch and the calculated ratio of escapement to catch. Rounsefell (1958) used a similar method for estimating the escapement to Karluk Lake prior to 1921; however, I attempted to correct for an apparent trend in the ratio (Fig. 7).

The predicted ratios were estimated by linear interpolation:

$$y = y_0 + \frac{y_1 - y_0}{x_1 - x_0}(x - x_0)$$

where x_0 = 1936,

y_0 = average ratio of escapement to catch for the period 1933-37 and 1939,

x_1 = 1951,

y_1 = average ratio of escapement to catch for the period 1949-53,

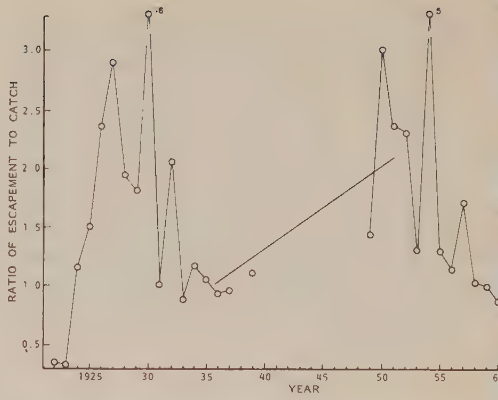

Figure 7.—Trend in the ratio of escapement to catch for C sockeye salmon, 1922-66. Ratios read from the straight lin used where data were missing, 1940-48.

x = year in which an estimate of escapemer catch was desired,

y = estimated ratio of escapement to catc

The predicted ratios were calculated from:

$$y = 1.03 + \frac{(2.10 - 1.03)}{(1951 - 1936)}(x - 1936).$$

The estimates were calculated from the ratio and for each of the years and compared with qualit scriptions of the yearly runs (Alaska Fishery a Seal Industries 1938, 1940-48) (Table 4). The estima 1938 is in close agreement with the figures s Alaska Fishery and Fur-Seal Industries (1938). mate of the escapement for 1940 is far from that Alaska Fishery and Fur-Seal Industries (1949); hov since no rationale is given for the published fig one calculated from the ratio of escapement to c used. Although the quantitative estimates an tative descriptions in Table 4 are not directly co able, they do seem to agree in magnitude.

Catches, Escapements, and Total Runs by Stock

Estimated migration times and delays **fishery, lagoon, and weir.**—Regulation of the Ch fishery requires knowledge of the daily total run, the total of the daily catch and daily esca Escapement was counted at the weir in Chign The daily catch could not be added to the escapeme the same day because of the migration time bet fishing area and weir. In addition, until 1966, fish were caught in significant numbers only in one by fishing area that was within the managemen trict. Migration times must be considered befo and escapement data can be combined.

Travel time between Cape Kumlik and Chignik —Starting in 1960 some purse seine boats in the management area began catching significant mbers of sockeye salmon in Aniakchak Bay and its stern terminus, Cape Kumlik, which is 72 km (45 mi) hignik Lagoon. Since that time tagging studies own that almost 95% of the sockeye salmon in is area are bound for Chignik Lagoon (Lechner[16]). In der to assign these fish to the catch of a given day in Lagoon, one must know the migration time from umlik to Chignik Lagoon. Travel time can be imated from the interval between the release of fish gged at Aniakchak Bay and the recovery of the same hignik Lagoon. Fish were tagged in Aniakchak Richardson[17] on 7 July 1963 during a closed hing period. The commercial fishery in the district re- perations on 8 July at 0600 h and continued oper- om 0600 to 1800 h each day through 12 July. The cove of tagged fish in Chignik Lagoon reached a peak lays after release (Fig. 8). Hartt (1966) has shown that delays the migration of mature sockeye salmon igh seas about 1 day. It appears from Figure 8 at many sockeye salmon can travel from Cape Kumlik Chignik Lagoon in 1 day, allowing 1 day for tagging his is a rate of travel of about 72 km (45 mi) per rtt (1966) has shown that the rate of travel for returns to Bristol Bay is as much as 56 km (35 mi) per day, becoming faster as the fish near the coast.

Travel time between Chignik Lagoon and Chignik weir.—The commercial catch in Chignik Lagoon on a given day is not taken from the same group of fish that are counted through the weir on the same day; the migration time between the fishing area and the weir must be considered. Normally, sockeye salmon move upstream from the lagoon on each high tide and pass immediately through the weir; few fish loiter in the river downstream from the weir. In tagging experiments to determine time of entry of the stocks, fish tagged and released in Chignik Lagoon during closed fishing periods were later counted as they passed through the weir. In addition, other fish were tagged and released immediately downstream from the weir and these tagged fish also were counted as they passed through the weir. Since the same sampling gear (seine), type of tags (25 mm diameter disks), and tagging crew were used in both tagging operations, the difference between migration times through the weir for the two groups of fish should reflect the migration time between the lagoon and weir (Figs. 9, 10; Table 5).

Two results are apparent from the tagging data: 1) Tagging delayed migration approximately 1 day, i.e., fish tagged immediately downstream from the weir did not pass through until about 1 day later as shown from the mode in Figure 9; and 2) assuming a delay in migration of 1 day due to tagging, the migration time from Chignik Lagoon to the weir was about 2 days. Since catch and escapement are recorded by 1-day intervals, a 2-day lag between the catch and escapement was used as the

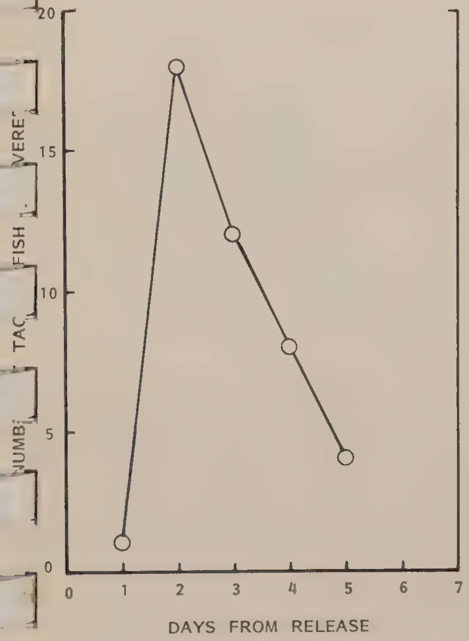

Figure 8.—Numbers of tagged sockeye salmon re- ered in Chignik Lagoon from day 1 to 5 after ease of fish tagged at Aniakchak Bay in July 1963 (data from Richardson, see text footnote 17).

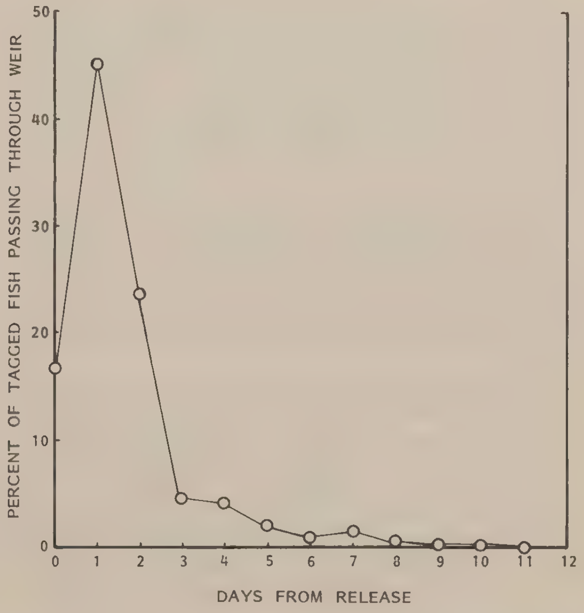

Figure 9.—Numbers of days between release and passage through the Chignik River weir for sockeye salmon tagged and released immediately below the weir, 1962-66 (Dahlberg 1968).

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r, J. 1969. Identification of red salmon stocks taken in the e Kumlik - Aniakchak Bay fishery, Chignik area, 1967. Alaska Dep. h Game Inf. Leafl. 133, 32 p.

dson, T. H. 1963. Aniakchak tagging program. Alaska Game, Juneau, 2 p.

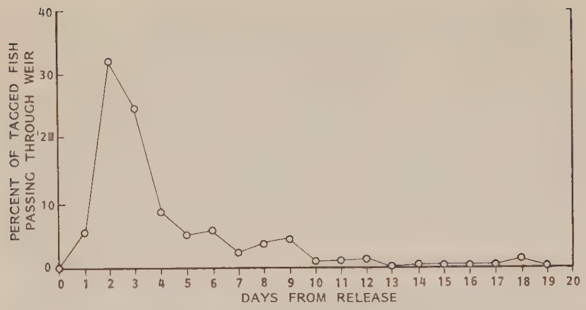

Figure 10.—Numbers of days between release and passage through the Chignik River weir for sockeye salmon tagged and released at Chignik Lagoon, 1962-66 (Dahlberg 1968).

Table 5.—Average duration of time from release to passage through the weir for sockeye salmon tagged in Chignik Lagoon and sockeye salmon tagged immediately below the Chignik River weir (combined data from 1949, 1962-66) (Dahlberg 1968).

Tagging location	Number of tagged fish counted through weir	Average time from release to passage through weir (days) Mean	Median	Mode
Lagoon	488	4.16	2.48	2.00
Weir	306	1.60	0.73	1.00
Difference	—	2.56	1.75	1.00

correction factor for the migration time between the lagoon and weir.

Separation of stocks by time of entry.—For management purposes, the sockeye salmon runs to the Chignik watershed are considered to be composed of two stocks: Chignik Lake stock and Black Lake stock (Dahlberg and Phinney[18]). Counting the catch and escapement of the two stocks is complicated. The two stocks travel through the same fishing area and trunk stream on their spawning migration, and their times of entry overlap. They do segregate on the spawning grounds, and their peak spawning activity generally occurs at different times.

Results of preliminary tagging studies in 1952, 1959, 1960, and 1961 indicated 1) that most of the fish entering Chignik Lagoon in early June were bound for the spawning areas of Black Lake and Black River tributaries, and 2) that fish entering in late July were bound for the spawning areas of Chignik Lake and certain Black River tributaries (Narver and Dahlberg 1964; Roos, see footnote 6).

The FRI conducted more intensive tagging studies from 1962 to 1966 to determine the consistency of timing of the runs and to measure overlap in entry time between the two stocks. Colored, 25 mm diameter disk tags were used in all the experiments; a different color combination was used during each tagging session. Recovery was by foot survey of each major spawning area at the peak of spawning (Table 6).

Table 6.—Summary of tagging experiments to determ time of entry of the sockeye salmon stocks of Chignik, 1962-66 (Dahlberg 1968).

Year	Total fish tagged	Total fish recovered	Percentage recovered	Tagging locati
1962	966	120	12	Lagoon a
1963	1,411	165	12	Weir
1964	1,658	175	11	Lagoon and
1965	1,448	150	10	Lagoon a
1966	1,816	160	9	Lagoon a
Total	7,299	770	11	

I classified the tagged fish into early-season season spawners and calculated their relative pe ages for each tagging date (early spawning peaked first week of August, and late spawning peak last week of August and early September). Bec ging sites varied between the lagoon and weir, all t dates were standardized to correspond with re the weir. Dates of tagging at the lagoon were ad compensate for the 2-day migration between th and weir.

To obtain a quantitative estimate of the pro each stock present in the catch and escapem given day, I sought a suitable mathematical mode approach was to consider the proportion of a stoc ent on a given day as a quantal response to pendent variable (time) and proceed with probi (Finney 1952). However, another approach to ana data of this nature was proposed by Moore and (1967), namely:

$$P = \frac{1}{1 + e^{-(a + bt)}} + \epsilon$$

where P = proportion of early spawners,
$1\text{-}P$ = proportion of late spawners,
e = base of Napierian system of loga
t = coded time in days measured June (day 1),
a, b = parameters estimated from studies,
ϵ = error term, assumed random.

A method of nonlinear least squares which uti techniques of steepest descent and linearizatio 1964) was used to fit curves to data collected in ea and to all tagging data combined (Fig. 11, Table

The entry pattern was nearly the same from year, but the time of entry changed slightly (the 1962 all fall to the left, or earlier entry; whereas, t for 1965 and 1966 are to the right, or later entry). entry might be expected to vary with annua ations in environmental conditions, such as, wea water temperatures; nonetheless, the curves can to separate approximately the early and late spa entry time and to indicate the daily proportio stock in the fishery and escapement.

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[18] Dahlberg, M. L., and D. E. Phinney. 1967. Studies of mature sockeye salmon at Chignik, 1966. Univ. Washington, Fish. Res. Inst. Circ. 67-7, 41 p.

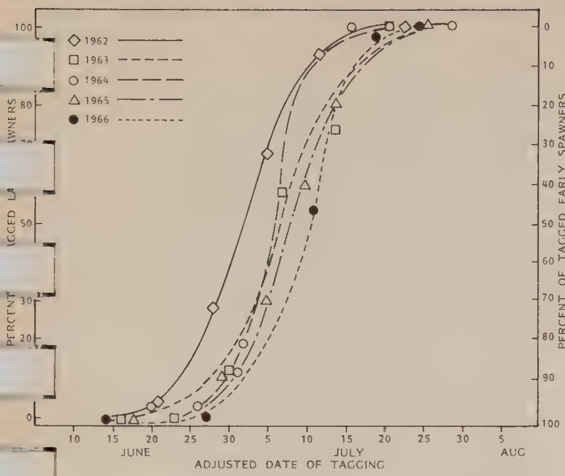

Figure 11.—Patterns of time of entry for tagged Black Lake and Chignik Lake sockeye salmon, 1962-66 (Dahlberg 1968).

Table 7.—Estimates of $\hat{a}$, $\hat{b}$, and $\hat{s}_{p/t}$ for tagging studies of time of entry of Chignik sockeye salmon, 1962-66, after the formula of Moore and Zeigler (1967), see text.

Year	$\hat{a}$	$\hat{b}$	$\hat{s}_{p/t}$	Number of observations
1962	−4.562	0.254	0.010	5
1963	−5.252	0.228	0.058	6
1964	−9.040	0.422	0.013	6
1965	−6.084	0.250	0.007	6
1966	−7.741	0.295	0.031	7
Combined	−5.451	0.239	0.090	30

To precisely regulate the escapement to the Chignik sys m, it is imperative to know where the progeny of the us spawning groups are reared, because manage- is based on the nursery area carrying capacity of each lake. A knowledge of the time of entry of early- and eason spawners is not adequate in itself, because all rogeny of the Black River tributary spawners (early season and late season) are reared in Chignik Lake (Narver 1966). About 13% of the early spawners use the (Table 8).[19] The progeny of the remainder of the spawners (which utilize the Black Lake tributaries) are reared in Black Lake; whereas, all the progeny of the late spawners are reared in Chignik Lake. On the average, the portion of the escapement for a given date whose progeny will be reared in Black Lake is the value read from the entry curve for the year in question (Fig. 11) minus 13%, the part of the escapement whose progeny is reared in Chignik Lake. This relationship implies that all Black Lake fry remain in Black Lake; this condition may not hold true in every year.

Table 8.—Proportions of Black River spawners in the early sockeye salmon escapements, 1960-66 (Dahlberg 1968).

Proportion of Black River spawners							Geometric
1960	1961	1962	1963	1964	1965	1966	mean
0.264	0.279	0.279	0.060	0.079	0.031	0.158	0.125

Calculation of catches and escapements by stock.—The information on catches and escapements was processed by computer program after the records had been compiled and estimated portions collated with the observed data (Dahlberg see footnote 15). The daily catches and escapements were divided into Chignik Lake and Black Lake stocks on the basis of the time of entry relationship. Time of entry was determined from tagging studies and the distribution of spawners on the spawning grounds. For years in which these data were not available, the average relationship was used. Catches were adjusted to allow for migration time from Cape Kumlik to Chignik Lagoon and the migration time between the lagoon and counting weir. Escapements of the two stocks were corrected for weir leakage (Lechner[20]) and the proportion of Black River spawners in the early escapements.

Estimates of the total catches by stock for the years 1888-1921 were produced from the computer program (Table 9). Table 10 presents the catches, escapements,[21] and runs by stock for the years 1922-66. Table 11 presents ratios of escapement to catch, rates of exploitation, and percentages of escapement for each stock. Figures 12 through 15 show the data in graphical form.

Beginning in 1967, summaries of the annual catch and escapement of the runs of sockeye salmon to Chignik have been reported by either FRI (Dahlberg and Phinney see footnote 18; Parr and Pedersen;[22] Wells and Parr[23]) or the Alaska Department of Fish and Game (Phinney and Lechner;[24] Pedersen and Seibel;[25]

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percentage of early spawners in the Black Lake tributaries is ned from aerial surveys of the spawning grounds in each year. The total number of spawners in Black River tributaries divided by the total number of spawners counted on all early spawning areas is the propor- d. For the years before 1960 the geometric mean ratio for the years was used. The proportion of Black River spawners observed each m 1960 to 1966 is shown in Table 8. A test of the consistency of using aerial survey data to calculate the Black River proportions of the early escapement was conducted in 1965. An Alaska Department of Fish and management biologist aerially surveyed the early spawning and from his counts determined a proportion of 0.0308 Black spawners; he accounted for 76% of the early escapement. On the same day, I made the same survey using the same airplane with the same pilot. I calculated a proportion of 0.0312 Black River spawners and ac- for 53% of the early escapement. Thus, although the total counts uite different, both observed the same relative proportion of spawners in Black River tributaries.

[20] Jack Lechner, Area Management Biologist, Alaska Department of Fish and Game, pers. commun., August 1965.

[21] Includes estimates of missing data for certain years as described previously. See also Table 6.

[22] Parr, W. H., Jr., and P. C. Pedersen. 1969. Studies of adult sockeye salmon at Chignik in 1968. Univ. Washington, Fish. Res. Inst. Circ. 69-16, 40 p.

[23] Wells, J. W., and W. H. Parr. 1971. Studies of adult sockeye salmon (*Oncorhynchus nerka*) at Chignik, Alaska, in 1969 and 1970. Univ. Washington, Fish. Res. Inst. Circ. 71-7, 61 p.

[24] Phinney, D. E., and J. Lechner. 1969. Studies of adult Chignik sockeye salmon in 1967. Alaska Dep. Fish Game Inf. Leafl. 130, 43 p.

[25] Pedersen, P. C., and M. C. Seibel. 1970. Forecast of the 1970 Chignik system red salmon run. Alaska Dep. Fish Game Inf. Leafl. 144, 24 p.

Table 9.—Summary of estimated catches by the fishery of Chignik sockeye salmon by stock, 1888-1921 (Dahlberg 1968).

Year	Chignik Lake	Black Lake	Total
1888	Na[1]	Na	13,000
1889	Na	Na	560,000
1890	Na	Na	453,000
1891	Na	Na	775,000
1892	Na	Na	522,000
1893	Na	Na	600,000
1894	Na	Na	600,000
1895	377,820	305,499	683,319
1896	615,671	234,329	850,000
1897	424,084	340,916	765,000
1898	797,466	367,953	1,165,419
1899	382,164	521,585	903,749
1900	588,532	458,839	1,047,371
1901	730,901	176,449	907,350
1902	895,888	886,127	1,782,015
1903	899,462	250,528	1,149,990
1904	1,409,452	280,190	1,689,642
1905	981,906	315,209	1,297,115
1906	1,112,235	211,349	1,323,584
1907	1,284,349	338,638	1,622,987
1908	1,208,984	421,693	1,630,677
1909	1,427,100	303,704	1,730,804
1910	978,174	336,498	1,314,672
1911	956,734	120,861	1,077,595
1912	949,857	380,975	1,330,832
1913	616,174	217,046	833,220
1914	795,200	261,429	1,056,629
1915	828,295	501,736	1,330,031
1916	710,934	291,977	1,002,911
1917	1,227,044	229,422	1,456,466
1918	1,429,709	112,998	1,542,707
1919	774,379	110,559	884,938
1920	1,407,882	364,828	1,772,710
1921	1,497,970	330,887	1,828,857

[1]Na = Not available.

Pedersen and Petersen[26]). Annual reports for the Chignik Management District are compiled each year by the area management biologist, Alaska Department of Fish and Game, and filed with the regional office in Kodiak, Alaska. Detailed records of the runs by stock, age group, and sex for the period 1922-66 can be found in Dahlberg (1968).

I used the information on age composition, catch, and escapement to estimate spawner-return relationships for the two stocks of sockeye salmon in the Chignik River system (Dahlberg 1973). Subsequent estimates of target escapements from these spawner-return functions have been considered by the management agency in controlling the annual catch.

SUMMARY

1. The abundance of stocks of sockeye salmon at Chignik, Alaska, decreased from an average of 1.9 million during the period 1922-39 to an average of 0.9 million during the period 1949-66. The average rate of exploitation during the two periods was nearly th same—0.428 in the early period and 0.422 in cent period.
2. The high-seas and coastal distributions of Chign sockeye salmon were investigated to determin whether or not Chignik sockeye salmon wer cepted by fisheries along the coast of the Ala ninsula. The Cape Kumlik fishery and, later, the Ca Igvak fishery harvest an important portion of th sockeye salmon bound for Chignik. This catch be counted as part of the annual Chignik ru
3. Chignik sockeye salmon have been exploited sinc 1888; several companies operated canneries in ly phase of the fishery. The salmon canning i coordinated their operations in the 1930's. Fro 195 through 1966, two companies operated in the are Chignik Fisheries Company and the Alaska Association.
4. Enforced regulation of the fishery did not exist befor 1922; after that year, management agents were sta tioned at Chignik each year to inspect the fishi during periodic closures. The White Act requ[illegible] a escapement equal to 50% of the yearly run; this re quirement was met in most years.
5. Catch records and weir counts were used as a b studying the productivity of the system during th last 40 yr. Since there were no escapement record from 1940 through 1948, a ratio of escapement t was used to estimate the missing data.
6. Separation of the catch and escapement records fo the two stocks was facilitated by time-of-en lationship. Results from tagging studies of were used to estimate the relationship; an averag time of entry curve was used to analyze the record before 1962.
7. Estimated annual catches and escapements f[illegible] eac of the two stocks were compiled for the period 1922-6 based upon the methods summarized above.

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Table 10.—Summary of estimated catches and escapements of Chignik sockeye salmon by stock, 1922-66 (Dahlberg 1968).

	Catch			Escapement			Total run		
Year	Chignik Lake	Black Lake	Total	Chignik Lake	Black Lake	Total	Chignik Lake	Black Lake	Total
1922	900,823	346,011	1,246,834	352,807	86,421	439,228	1,253,630	432,432	1,686,062
1923	562,316	80,556	642,872	213,781	4,642	218,423	776,097	85,198	861,295
1924	767,424	110,937	878,361	910,521	121,983	1,032,504	1,677,945	232,920	1,910,865
1925	436,985	260,999	697,984	677,566	386,364	1,063,930	1,114,551	647,363	1,761,914
1926	173,161	242,054	415,215	695,314	289,009	984,323	868,475	531,063	1,399,538
1927	303,401	137,566	440,967	429,525	857,881	1,287,406	732,926	995,447	1,728,373
1928	774,667	8,595	783,262	1,020,520	507,353	1,527,873	1,795,187	515,948	2,311,135
1929	689,123	359,861	1,048,984	914,307	995,832	1,910,139	1,603,430	1,355,693	2,959,123
1930	27,306	888	28,194	359,405	92,955	452,360	386,711	93,843	480,554
1931	503,584	206,256	709,840	631,986	96,201	728,187	1,135,570	302,457	1,438,027
1932	871,112	704,130	1,575,242	1,113,859	2,151,734	3,265,593	1,984,971	2,855,864	4,840,835
1933	345,469	249,452	594,921	310,088	223,913	534,001	655,557	473,365	1,128,922
1934	525,294	583,048	1,108,342	447,642	866,890	1,314,532	972,936	1,449,938	2,422,874
1935	409,893	209,449	619,342	462,469	194,636	657,105	872,362	404,085	1,276,447
1936	453,914	526,811	980,725	376,838	548,039	924,877	830,752	1,074,850	1,905,602
1937	422,254	207,064	629,318	406,618	205,613	612,231	828,872	412,677	1,241,549
1938	260,879	150,111	410,990	305,827	175,972	481,799	566,706	326,083	892,789
1939	652,780	827,580	1,480,360	512,754	1,142,852	1,655,606	1,165,534	1,970,432	3,135,966
1940	116,336	134,098	250,434	152,957	176,307	329,264	269,293	310,405	579,698
1941	383,764	270,145	653,909	531,904	374,420	906,324	915,668	644,565	1,560,233
1942	354,518	303,987	658,505	516,621	442,981	959,602	871,139	746,968	1,618,107
1943	788,636	459,182	1,247,818	1,205,418	701,859	1,907,277	1,994,054	1,161,041	3,155,095
1944	219,545	182,431	401,976	351,212	291,844	643,056	570,757	474,275	1,045,032
1945	90,563	130,390	220,953	151,326	217,882	369,208	241,889	348,272	590,161
1946	424,682	444,337	869,019	739,884	774,130	1,514,014	1,164,566	1,218,467	2,383,033
1947	768,694	1,316,128	2,084,822	1,393,990	2,386,733	3,780,723	2,162,684	3,702,861	5,865,545
1948	166,244	204,085	370,329	313,319	384,637	697,956	479,563	588,722	1,068,285
1949	418,156	124,390	542,546	574,715	213,269	787,984	992,871	337,659	1,330,530
1950	318,450	34,742	353,192	861,070	206,270	1,067,340	1,179,520	241,012	1,420,532
1951	143,521	115,494	259,015	490,899	125,126	616,025	634,420	240,620	875,040
1952	20,393	106,675	127,068	260,540	34,155	294,695	280,933	140,830	421,763
1953	109,450	185,738	295,188	221,408	168,375	389,783	330,858	354,113	684,971
1954	19,232	72,334	91,566	277,912	184,953	462,865	297,144	257,287	554,431
1955	168,987	179,539	348,526	201,409	256,757	458,166	370,396	436,296	806,692
1956	421,251	246,442	667,693	483,024	289,096	772,120	904,275	535,538	1,439,813
1957	224,757	77,423	302,180	328,779	192,479	521,258	553,536	269,902	823,438
1958	179,949	141,180	321,129	212,594	120,862	333,456	392,543	262,042	654,585
1959	251,547	165,000	416,547	308,645	112,226	420,871	560,192	277,226	837,418
1960	418,356	274,048	692,404	357,230	251,567	608,797	775,586	525,615	1,301,201
1961	278,609	53,852	332,461	254,970	140,714	395,684	533,579	194,566	728,145
1962	292,528	71,562	364,090	324,860	167,602	492,462	617,388	239,164	856,552
1963	323,080	80,258	403,338	200,314	332,536	532,850	523,394	412,794	936,188
1964	427,940	128,950	556,890	166,625	137,073	303,698	594,565	266,023	860,588
1965	152,521	477,032	629,553	163,151	307,192	470,343	315,672	784,224	1,099,896
1966	143,098	79,696	222,794	183,525	383,545	567,070	326,623	463,241	789,864

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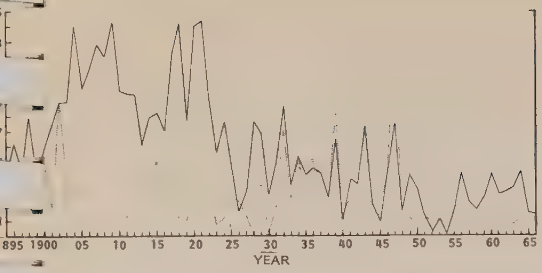
Table 11.—Selected ratios of catch and escapement statistics for Chignik Lake, Black Lake, and total runs, 1922-66.

	Chignik Lake				Black Lake				Total run			
Year	Catch/ escape- ment	Escape- ment/ catch	Rate of exploi- tation	Escape- ment (prop)	Catch/ escape- ment	Escape- ment/ catch	Rate of exploi- tation	Escape- ment (prop)	Catch/ escape- ment	Escape- ment/ catch	Rate of exploi- tation	Escape- ment (prop)
1922	2.553	0.391	0.718	0.281	4.003	0.249	0.800	0.199	2.838	0.352	0.739	0.260
1923	2.630	0.380	0.724	0.275	17.353	0.057	0.945	0.054	2.943	0.339	0.746	0.253
1924	0.842	1.186	0.457	0.542	0.909	1.099	0.476	0.523	0.850	1.175	0.459	0.540
1925	0.644	1.550	0.392	0.607	0.675	1.480	0.403	0.596	0.656	1.524	0.396	0.603
1926	0.249	4.015	0.199	0.800	0.837	1.193	0.455	0.544	0.421	2.370	0.296	0.703
1927	0.706	1.415	0.413	0.586	0.160	6.236	0.138	0.861	0.342	2.919	0.255	0.744
1928	0.759	1.317	0.431	0.568	0.016	59.028	0.016	0.983	0.512	1.950	0.338	0.661
1929	0.753	1.326	0.429	0.570	0.361	2.767	0.265	0.734	0.549	1.820	0.354	0.645
1930	0.075	13.162	0.070	0.929	0.009	104.679	0.009	0.990	0.062	16.044	0.058	0.941
1931	0.796	1.254	0.443	0.556	2.144	0.466	0.681	0.318	0.974	1.025	0.493	0.506
1932	0.782	1.278	0.438	0.561	0.327	3.055	0.246	0.753	0.482	2.073	0.325	0.674
1933	1.114	0.897	0.526	0.473	1.114	0.897	0.526	0.473	1.114	0.897	0.526	0.473
1934	1.173	0.852	0.539	0.460	0.672	1.486	0.402	0.597	0.843	1.186	0.457	0.542
1935	0.886	1.128	0.469	0.530	1.076	0.929	0.518	0.481	0.942	1.060	0.485	0.514
1936	1.204	0.830	0.546	0.453	0.961	1.040	0.490	0.509	1.060	0.943	0.514	0.485
1937	1.038	0.962	0.509	0.490	1.007	0.992	0.501	0.498	1.027	0.972	0.506	0.493
1938	0.853	1.172	0.460	0.539	0.853	1.172	0.460	0.539	0.853	1.172	0.460	0.539
1939	1.273	0.785	0.560	0.439	0.724	1.380	0.420	0.580	0.894	1.118	0.472	0.527
1940	0.760	1.314	0.432	0.567	0.760	1.314	0.432	0.567	0.760	1.314	0.432	0.567
1941	0.721	1.386	0.419	0.580	0.721	1.386	0.419	0.580	0.721	1.386	0.419	0.580
1942	0.686	1.457	0.406	0.593	0.686	1.457	0.406	0.593	0.686	1.457	0.406	0.593
1943	0.654	1.528	0.395	0.604	0.654	1.528	0.395	0.604	0.654	1.528	0.395	0.604
1944	0.625	1.599	0.384	0.615	0.625	1.599	0.384	0.615	0.625	1.599	0.384	0.615
1945	0.598	1.670	0.374	0.625	0.598	1.671	0.374	0.625	0.598	1.670	0.374	0.625
1946	0.573	1.742	0.364	0.635	0.573	1.742	0.364	0.635	0.573	1.742	0.364	0.635
1947	0.551	1.813	0.355	0.644	0.551	1.813	0.355	0.644	0.551	1.813	0.355	0.644
1948	0.530	1.884	0.346	0.653	0.530	1.884	0.346	0.653	0.530	1.884	0.346	0.653
1949	0.727	1.374	0.421	0.578	0.583	1.714	0.368	0.631	0.688	1.452	0.407	0.592
1950	0.369	2.703	0.269	0.730	0.168	5.937	0.144	0.855	0.330	3.021	0.248	0.751
1951	0.292	3.420	0.226	0.773	0.923	1.083	0.479	0.520	0.420	2.378	0.296	0.704
1952	0.078	12.775	0.072	0.927	3.123	0.320	0.757	0.242	0.431	2.319	0.301	0.698
1953	0.494	2.022	0.330	0.669	1.103	0.906	0.524	0.475	0.757	1.320	0.430	0.569
1954	0.069	14.450	0.064	0.935	0.391	2.556	0.281	0.718	0.197	5.054	0.165	0.834
1955	0.839	1.191	0.456	0.543	0.699	1.430	0.411	0.588	0.760	1.314	0.432	0.567
1956	0.872	1.146	0.465	0.534	0.852	1.173	0.460	0.539	0.864	1.156	0.463	0.536
1957	0.683	1.462	0.406	0.593	0.402	2.486	0.286	0.713	0.579	1.724	0.366	0.633
1958	0.846	1.181	0.458	0.541	1.168	0.856	0.538	0.461	0.963	1.038	0.490	0.509
1959	0.815	1.226	0.449	0.550	1.470	0.680	0.595	0.404	0.989	1.010	0.497	0.502
1960	1.171	0.853	0.539	0.460	1.089	0.917	0.521	0.478	1.137	0.879	0.532	0.467
1961	1.092	0.915	0.522	0.477	0.382	2.612	0.276	0.723	0.840	1.190	0.456	0.543
1962	0.900	1.110	0.473	0.526	0.426	2.342	0.299	0.700	0.739	1.352	0.425	0.574
1963	1.612	0.620	0.617	0.382	0.241	4.143	0.194	0.805	0.756	1.321	0.430	0.569
1964	2.568	0.389	0.719	0.280	0.940	1.062	0.484	0.515	1.833	0.545	0.647	0.352
1965	0.934	1.069	0.483	0.516	1.552	0.643	0.608	0.391	1.338	0.747	0.572	0.427
1966	0.779	1.282	0.438	0.561	0.207	4.812	0.172	0.827	0.392	2.545	0.282	0.717
1922-1939:												
Mean	1.018	1.883	0.463	0.537	1.844	10.456	0.431	0.569	0.965	2.163	0.438	0.561
95% confidence limits												
Upper	1.340	3.334	0.538	0.613	3.822	23.966	0.551	0.689	1.340	3.918	0.518	0.641
Lower	0.696	0.432	0.387	0.461	−0.132	−3.053	0.311	0.448	0.589	0.409	0.358	0.481
1949-1966:												
Mean	0.841	2.733	0.411	0.588	0.873	1.982	0.411	0.588	0.779	1.687	0.413	0.586
95% confidence limits												
Upper	1.127	4.738	0.495	0.671	1.223	2.763	0.495	0.672	0.974	2.220	0.473	0.646
Lower	0.555	0.727	0.328	0.504	0.523	1.201	0.327	0.504	0.583	1.153	0.353	0.526
Combined:												
Mean	0.930	2.308	0.437	0.562	1.359	6.219	0.421	0.578	0.872	1.925	0.426	0.574
95% confidence limits												
Upper	1.136	3.492	0.491	0.616	2.326	12.802	0.490	0.648	1.075	2.799	0.473	0.621
Lower	0.723	1.125	0.383	0.508	0.391	−0.364	0.351	0.509	0.668	1.051	0.378	0.526



.—Calculated catches of Chignik Lake (solid line) and k Lake (dotted line) sockeye salmon, 1895-1966, based on time of of the stocks in recent years (Dahlberg 1968).

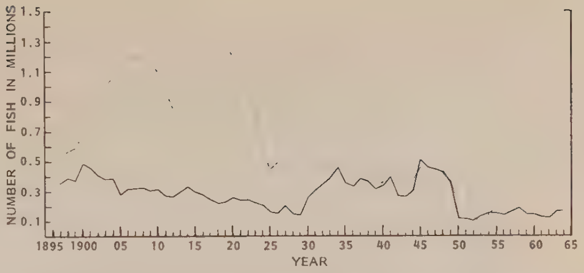


Figure 13.—Catch trends for Chignik Lake (dotted line) and Black Lake (solid line), 1895-1966, smoothed by a moving average of 5 (Dahlberg 1968).

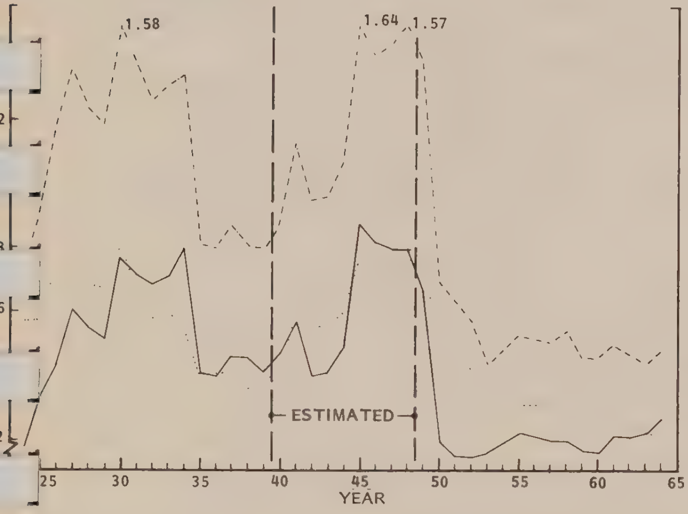
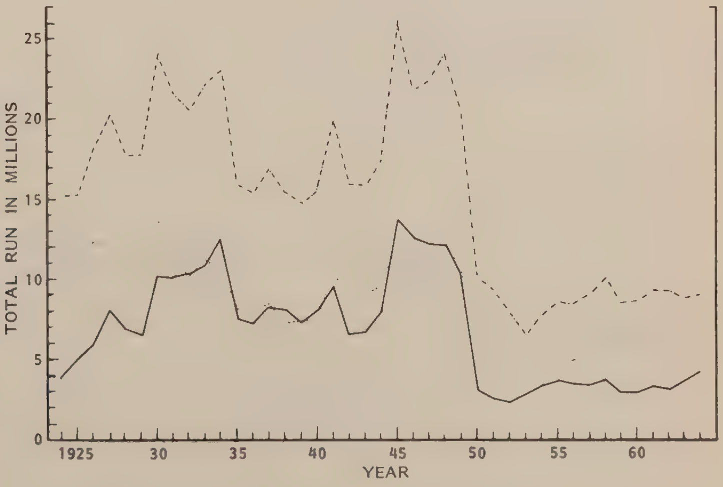


Figure 14.—Escapement trends for Chignik Lake (dotted line), Black Lake (solid line), and combined stocks (broken line), 1922-66, smoothed by a moving average of 5 (Dahlberg 1968).

5.—Trends in total run for Chignik Lake ne), Black Lake (solid line), and combined s (broken line), 1922-66, smoothed by a moving age of 5 (Dahlberg 1968).



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A Historical and Descriptive Account of Pacific Coast Anadromous Salmonid Rearing Facilities and a Summary of Their Releases by Region, 1960-76

Roy J. Wahle and Robert Z. Smith

September 1979

U.S. DEPARTMENT OF COMMERCE
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A Historical and Descriptive Account of Pacific Coast Anadromous Salmonid Rearing Facilities and a Summary of Their Releases by Region, 1960-76

ROY J. WAHLE and ROBERT Z. SMITH[1]

ABSTRACT

A brief history of the artificial culture of salmonid fishes in North America is presented. The report contains a Pacific coast section followed by sections for each of six major regions on the coast: Alaska, British Columbia, Washington coastal and Puget Sound, Columbia Basin, Oregon coastal, and California. The Columbia Basin is further divided into three subregions. The Pacific coast section provides information on current production of anadromous salmon (*Oncorhynchus* spp.) and trout (*Salmo* spp.). Each regional or subregional section contains a short history and background, a map with current rearing facilities located, a general hatchery information table, and migrant release tables summarized by species. In the final portion of the report, changes in numbers of facilities, species reared, rearing techniques, and size at time of release are discussed.

INTRODUCTION

Vhen the report on the "Releases of Anadromous mon and Trout from Pacific Coast Rearing Facilities, 1960 to 1973" by Roy J. Wahle, William D. Parente, P la J. Jurich, and Robert R. Vreeland (1975) was lished, it had three main objectives: 1) to provide pa t and present trends in artificial production of Pacific coast anadromous fish, 2) to supply base information ded for analysis of production practices, and 3) to g together in a single source, detailed release information from all anadromous fish rearing facilities in Alaska, British Columbia, Washington, Idaho, Oregon, and Cali ia. In fulfilling these objectives, it was necessary for hle et al. (1975) to be very detailed. We have prepared this summary report to provide the reader with a more readily usable, quick reference to anadromous fish luction on the Pacific coast, Alaska to California, n 1960 to 1976.

In addition to a section on interpretation and organiz tion, this report includes a general history section cov g artificial salmonid propagation in North America. history is followed by a coast-wide summary and sections for Alaska, British Columbia, Washington tal and Puget Sound, Columbia Basin, Oregon tal, and California. The last portion of this report deals with hatchery production trends. These include changes in numbers of hatcheries, species reared, rearing niques, and the size of fish at time of release.

he two appendix tables have been provided to allow maximum use of the informational tables in each regional section. Appendix Table 1 has an alphabetized f Pacific coast rearing facilities along with the region ach. This table can be used as an index for locating individual facilities in the report. Appendix Table 2 contains information on all State, Federal, or Provincial agencies rearing anadromous fish on the Pacific coast. It includes addresses, phone numbers, and people to contact with each of these agencies.

The Columbia Basin, containing portions of Washington, Idaho, and Oregon, has been handled separately because of: 1) the large geographical area drained by a common river system; 2) the constant interaction of diverse resource agencies and interested user groups; 3) the need for evaluation of production and habitat improvement measures within the Basin; and 4) the contribution and value of Columbia Basin anadromous salmonids to Pacific coast fisheries.

Each regional section includes a short history and background, a map with the facilities located, a general hatchery information table, and a release summary table. The general information table lists the approximate location, species reared, operating and funding agencies, year of construction, and the operational status in 1976 for the facilities in each region.

Unless otherwise cited, all historical information on early hatcheries has been based on Cobb (1931). One area of possible confusion to the reader concerns the use of agencies "names." During the years fish have been artificially propagated in the United States, many of the agencies concerned have undergone name changes. In this report, we have attempted to use agency names as taken from the literature rather than the names that may be in current use.

INTERPRETATION AND ORGANIZATION

Six species of salmon (*Oncorhynchus* spp.) and two of anadromous trout (*Salmo* spp.) are included in this report. Because of their current economic and recreational importance, the primary species considered are chinook, *O. tshawytcha*, and coho, *O. kisutch*, salmon, nd steelhead trout, *S. gairdneri.* The other species: hum, *O. keta,* pink, *O. gorbusha,* sockeye, *O. nerka,* and herry, *O. masu,* salmon, and sea-run cutthroat trout, *S. larki,* are presently reared on a limited basis and are included only if they were raised in the region being considered.

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[1] vironmental and Technical Services Division, National Marine ies Service, NOAA, 811 NE. Oregon Street, P.O. Box 4332, Portland, OR 97208.

We have further divided chinook salmon into three races (spring, summer, and fall) and steelhead trout into wo races (summer and winter). These designations are commonly used by all fisheries agencies rearing anadromous salmonids and are based for the most part on the season during which the adult fish return to freshwater. Rearing periods differ among the races of chinook salmon.

Releases of fish included in Wahle et al. (1975) were divided into two categories: migrants and submigrants. This was done to separate production releases from those necessitated by reducing numbers of fish to achieve "optimum" pond capacity levels. The definitions used were based on the best available knowledge of the ideal size at release for obtaining the greatest immediate seaward migration, but were not used as hard and fast rules. Exceptions were made in special cases if it was felt that a group of fish belonged in a different category than indicated by the definition.

The migrant and submigrant classifications used in this report should not be confused with the terms "fry," "fingerling," and "yearling" that we have included in the various history sections. "Fry" normally refers to fish released without any rearing, as soon as the yolk sac has been absorbed. "Fingerlings" can refer to any number of different sizes depending on the author and the species. Often "fry" and "fingerlings" refer to fish we would call submigrants. "Yearlings" in the historical literature normally refers to fish reared for a year in the hatchery before release. Depending on species, we might call these fish migrants.

As reported by Wahle et al. (1975), our definitions of migrants for each species are:

Spring and summer chinook salmon—those released after 12 mo of rearing or larger than 30/lb (15.1 g/fish).
Fall chinook salmon—those released after 90 days of rearing or larger than 300/lb (1.5 g/fish).
Coho salmon—those released after 12 mo of rearing or larger than 30/lb (15.1 g/fish).
Pink and chum salmon—those released after any period of feeding at the rearing facility.
Steelhead and sea-run cutthroat trout—those released after 12 mo of rearing or larger than 10/lb (45.4 g/fish).

Migrant criteria for sockeye and cherry salmon were not presented in Wahle et al. (1975). For those species, we have relied on the hatcheries or agencies involved to indicate whether each release was migrant in nature.

We define submigrants as those releases that do not meet migrant specifications. In the case of pink and chum salmon, submigrants would be any unfed fry released.

Data for this report was obtained from Wahle et al. (1975) and the appropriate State, Federal, and Canadi fishery management agencies.

HISTORY

Artificial propagation of salmonids began in Nor America in the mid-1800's. Theodatus Garlick of Cleveland, Ohio, in conjunction with H. A. Ackley, Succes fully artificially bred brook trout, *Salvelinus fontina* (Milner 1874). The first hatchery in North America was established by Seth Green at Mumford, N.Y., in 1864, and the first anadromous fish hatchery was built in N Castle, Canada, in 1866 for the purpose of taking Atla tic salmon, *Salmo salar,* eggs (Atkins 1874).

In the late 19th and early 20th centuries, efforts were made by Federal and various State commissions to int duce Pacific coast salmon into eastern waters. In 18 Livingston Stone was sent to California by the U.S. Commission of Fish and Fisheries to obtain salmon eggs for shipment to the east coast. He established the first Pa ic fish cultural station in 1872 on the McCloud Riv named after the then Commissioner of Fisheries, Spencer F. Baird. While the main purpose of this station was t shipment of eggs east, the Commission made a coope tive agreement with the State of California in which the State furnished part of the operating expense money in return for the station's releasing native fingerlings i the McCloud River. Eggs taken for shipment were k in baskets at the hatchery until the eyes of the embryo were visible. They were then packed in moss, crated, and taken by stagecoach to Red Bluff, Calif. From there, t traveled by train to San Francisco and then on to the e coast. To assure the survival of the eggs, it was necessary to continually dampen the moss in which they were packed. In the first year of operation, 50,000 eggs w taken, but 20,000 were lost due to difficulties experien in keeping the eggs cool prior to shipment. The remaining 30,000 eggs were shipped east and from th 7,000 fry were planted in Pennsylvania's Susquehar River (Stone 1874).

Before the attempts to transplant Pacific salmon to the eastern United States were discontinued, Pac coast salmon had been planted in a large number of r jor streams on the Atlantic coast, in the Mississippi drainage, and in the Great Lakes. Some of these transplants were moderately successful. From approximat 10,000 chinook salmon fingerlings planted in L Quinsigamond, Mass., 600 fish weighing between 0.68 and 2.27 kg were caught. Early plants of pink salmon in selected New England streams also met with some s cess. A female pink salmon weighing approximately kg was taken in the Penobscot River. Most of these transplants resulted in failures as the selected waters w either too warm or too turbid for salmon to survive. few runs that did become established either had so few returnees that they were not self sustaining or fishermen caught all the fish (Cobb 1931).

These early efforts at transplanting fish created a la demand for eggs. This demand resulted in construction of hatcheries in all the Pacific Coast States. After a short ti, the taking of eggs for transportation became sec-ry to augmenting runs in Pacific coast streams by rearing and releasing the fish (Stone 1874). From these beginnings emerged the Pacific coast salmon rearing in-ry.

PACIFIC COAST

ith today's increasing use of the fishery resource and the continuing degradation of the environment necessary for proper spawning and freshwater rearing of anadro-s salmonids, it has become necessary to augment ral production if we are to maintain viable sport and commercial fisheries. From 1960 through 1976 a total of 189 facilities, including 120 hatcheries and 69 rearing ponds and net pens, have made production releases for at least 1 yr. During this period, 3.44 billion migrant salmon and steelhead trout weighing over 105 million lb (47.6 million kg) have been released (Tables 1, 2). Annual migrant production of all species increased from 152 million fish weighing 1.7 million lb (0.77 million kg) at release in 1960 to 294 million fish weighing 11.1 million lb (5.03 million kg) in 1976.

Alaska

Most early Alaska hatcheries were located in the

Table 1.—Migrant releases of chinook and coho salmon and steelhead trout—Pacific coast[1] (in thousands).

Release	Fall chinook		Spring chinook		Summer chinook		Coho		Winter steelhead		Summer steelhead	
year	Number	Pounds[2]	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
1960	117,680.3	556.6	7,636.3	228.8	0.0	0.0	14,490.7	444.3	2,593.5	315.2	233.0	31.0
1961	103,220.8	672.7	5,315.2	197.9	0.0	0.0	26,148.8	864.6	2,522.8	314.6	674.5	97.3
1962	86,121.5	544.5	5,690.7	244.8	0.0	0.0	27,333.4	995.8	3,509.1	390.5	723.8	73.4
1963	99,806.7	658.9	9,421.1	370.1	0.0	0.0	30,987.2	1,123.5	2,922.8	332.9	1,336.4	146.8
1964	106,684.2	752.1	13,963.7	499.8	0.0	0.0	30,275.5	1,309.0	4,221.9	556.6	1,784.5	221.0
1965	95,918.6	740.6	7,302.7	303.7	0.0	0.0	34,746.8	1,516.8	4,216.2	536.5	1,660.4	185.2
1966	95,712.4	891.7	11,645.7	477.1	0.0	0.0	40,422.2	1,931.2	6,166.6	829.1	1,770.2	223.3
1967	96,386.1	885.8	14,063.7	644.6	0.0	0.0	40,276.6	2,059.9	5,784.1	774.2	3,316.5	401.2
1968	112,534.2	1,174.8	13,877.8	863.3	2,138.3	13.6	38,371.4	2,119.1	6,077.0	828.6	4,860.0	580.0
1969	124,125.1	1,266.4	10,392.1	804.6	2,121.3	20.2	47,988.0	2,814.4	6,380.0	886.1	4,814.1	593.9
1970	137,757.4	1,603.8	16,879.7	1,478.1	4,228.2	35.4	48,209.4	2,751.3	7,101.9	1,047.7	6,795.4	1,041.3
1971	168,388.9	1,706.2	14,726.1	1,151.0	2,184.5	37.0	51,182.3	3,039.6	8,733.5	1,090.6	8,143.4	1,091.5
1972	166,678.2	2,019.1	16,546.0	1,401.3	2,604.9	42.6	58,858.9	3,772.7	9,247.3	1,263.9	6,399.9	998.7
1973	162,515.8	2,266.4	17,604.5	1,761.6	2,312.6	34.3	53,400.0	3,178.5	8,680.1	1,243.3	8,111.9	972.5
1974	149,968.2	2,504.4	16,506.1	1,353.1	1,202.8	43.0	56,580.9	3,453.1	8,060.6	1,088.7	10,048.1	1,285.3
1975	157,707.6	2,554.7	21,389.5	1,848.6	120.8	3.1	60,936.3	3,854.5	7,376.7	1,067.2	7,126.3	1,068.1
1976	163,110.3	2,775.9	22,462.0	1,974.0	880.5	42.7	62,928.3	3,710.3	8,895.7	1,360.6	7,043.2	1,035.2
Total	2,144,316.3	23,574.6	225,422.9	15,602.4	17,793.9	271.9	723,136.7	38,938.6	102,489.8	13,926.3	74,841.6	10,045.7

[1] Data derived from Wahle et al. (1975) prior to 1974 and from appropriate State, Federal, and Provincial records thereafter.

[2] 1 lb = 0.454 kg.

Table 2.—Migrant releases of chum, pink, sockeye, and cherry salmon and sea-run cutthroat trout—Pacific coast[1] (in thousands).

Release	Chum		Pink		Sockeye		Cherry		Sea-run cutthroat	
year	Number	Pounds[2]	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
1960	5,031.6	8.8	555.5	2.5	3,177.0	69.2	0.0	0.0	155.4	42.8
1961	4,774.1	13.0	0.0	0.0	2,788.0	72.5	0.0	0.0	189.4	52.6
1962	1,859.3	4.6	145.7	0.5	2,224.0	43.8	0.0	0.0	292.0	77.6
1963	5,454.4	9.3	0.0	0.0	3,125.4	67.8	0.0	0.0	139.8	48.0
1964	3,358.5	6.9	525.3	0.9	3,364.0	58.8	0.0	0.0	258.7	64.3
1965	3,116.7	5.8	0.0	0.0	3,301.0	73.6	0.0	0.0	231.9	52.4
1966	1,785.4	6.0	421.0	1.3	73.0	1.6	0.0	0.0	395.9	95.3
1967	1,827.0	6.4	0.0	0.0	0.0	0.0	0.0	0.0	554.2	128.7
1968	1,264.3	3.7	602.8	1.4	0.0	0.0	0.0	0.0	561.6	121.3
1969	2,448.0	5.8	0.0	0.0	23.4	0.7	0.0	0.0	531.9	126.3
1970	1,563.0	4.4	774.9	2.4	0.0	0.0	0.0	0.0	639.5	139.8
1971	3,839.6	9.0	0.0	0.0	0.0	0.0	0.0	0.0	815.6	169.1
1972	5,624.2	17.2	1,957.9	5.1	2.5	(3)	0.0	0.0	491.8	122.0
1973	6,565.5	20.5	0.0	0.0	0.0	0.0	26.1	3.2	585.9	151.8
1974	10,012.1	34.1	1,211.9	3.5	0.0	0.0	44.4	4.3	462.3	112.4
1975	29,637.5	88.2	0.0	0.0	0.0	0.0	1.0	0.1	471.8	118.2
1976	23,779.9	86.6	4,850.4	8.7	16.2	0.6	0.5	0.1	496.9	132.5
Total	111,941.1	330.3	11,045.4	26.3	18,094.5	388.6	72.0	7.7	7,274.6	1,755.1

[1] Data derived from Wahle et al. (1975) prior to 1974 and from appropriate State, Federal, and Provincial records thereafter.

[2] 1 lb = 0.454 kg.

[3] Less than 100 lb.

southeastern part of the State. They were funded by fish canneries and reared primarily sockeye salmon. The first hatchery in the State was a co-op built in 1891 by several canneries in Karluk, Kodiak Island. This was not an auspicious beginning for salmon culture in Alaska as the hatchery stopped production after only 1 yr because of violent disagreements among the canneries' personnel over fishing rights in the area.

By the early 1900's private hatcheries were in operation on Kodiak, Kuiu, Baranof, Etolin, Revillagigedo, Chichagof, and Prince of Wales Islands, as well as on the mainland. These facilities operated for varying periods of time through 1936. The world's largest and most costly facility to that time, the Fortmann Hatchery, was constructed in 1901 by the Alaska Packer's Association at Loring, Revillagigedo Island. It had a capacity of hatching 110 million eggs.

From 1893, when records were first kept, to 1912, releases of fry increased from 600,000 to a maximum of 156 million, and then declined to 32.5 million in 1936 when the last facility closed. During the peak years, from 1905 to 1912, the private hatchery annual releases averaged over 106 million fish. Although most of the fish were sockeye, a few pink salmon were released from several of the facilities.

Until 1900, the operation of private hatcheries was voluntary. Thereafter, a Congressional Act required salmon canning companies in Alaska to operate hatcheries and, each year, release four sockeye salmon fry for each adult salmon of any species taken during the previous year. In addition, the companies were required to keep records of the numbers of fish spawned, eggs taken, percentage hatched, fry planted, and release locations. In 1902, the release ratio was increased to 10 fry for each salmon taken. Most companies either ignored the requirement or found it impossible to follow. Because of this, the regulation was modified in 1906 to reduce license fees and taxes for complying companies.

In 1905, the U.S. Bureau of Fisheries erected Alaska's first Federal hatchery on Yes Bay near Ketchikan. This station, along with another Bureau hatchery on Afognak Bay, Afognak Island, hatched and released primarily sockeye salmon along with a few pinks, coho, and steelhead trout fry. Numbers of fish released ranged from 6 million in 1906 to 142 million in 1910 and then declined to 22 million in 1928. In addition, these two hatcheries shipped at least 150 million eyed eggs to Oregon, Wa ington, and the New England States including Maine well as the Province of British Columbia. The two hatcheries operated until 1933 when, because of the Depression, funding at Federal hatcheries was cut by 4 All over the country, rearing programs were cut back nine hatcheries, including the two in Alaska, were shut down (Leach and James 1934).

Little effort other than some experiments w planting eyed eggs was expended on anadromous salm id production between 1936 and 1955. In 1955, the Deer Mountain Hatchery at Ketchikan hatched and rea coho and sockeye salmon. Some of the eggs for th plants, as well as those for some chinook salmon plants in 1965-66, came from the Green River in Washington. A hatchery near Fairbanks and the Deer Mountain Hat ery, as well as one operated on the Karluk River b sports group, released fall chinook salmon and steelhead trout during the late 1950's. Fire Lake Hatchery, near Anchorage, opened in 1956. While this facility mai reared trout for planting into lakes for resident fisher steelhead trout were also included in its program. Besides releasing a small number of steelhead trout fry, the hatchery also supplied eggs to the Fairbanks facility. these hatcheries except Fire Lake have ceased anad mous rearing operations. Since 1960, one additional hatchery, Crystal Lake, and four experimental rearing facilities (one rearing pond and three saltwater net pe have become operational (Table 3). Of the six, five e operated by the Alaska Department of Fish and Game (ADFG) and one by the National Marine Fisheries Se ice (NMFS). Four are located in southeastern Alaska two are near Anchorage (Fig. 1).

In addition to these rearing stations, ADFG also operates several chum and pink salmon incubation facili which release unfed fry. One, Kitoi Bay Hatchery Afognak Island, has been in operation since 1953 and has also released large numbers of sockeye salmon fry. Others have been constructed in the past 3 yr by ADFG Fish ies Rehabilitation Enhancement and Developm (FRED) Division using special monies appropriated by the State legislature. These incubation stations are being built to offset dramatic drops in Alaska's fish sto (Alaska Department of Fish and Game 1976).

Table 3.—Anadromous fish rearing facilities—Alaska, 1960-76.

Facility	General location	Operating agency[1]	Species reared during year span[2]	Anadromous releases in 1976	Year anadromous operation began	Funding agency[1]
Hatcheries						
Crystal Lake	Petersburg	ADFG	sc, co, sh	Yes	1972	ADFG, Anadrom Fish Act [3]
Fire Lake	Anchorage	ADFG	sc, co	Yes	1956	ADFG
Ponds and net pens						
Halibut Cove Lagoon net pen	Homer	ADFG	sc, co	Yes	1972	ADFG
Little Port Walter net pen	S.E. Baranof Island	NMFS	sc, co, sk	Yes	1967	NMFS
Mendenhall Pond	Juneau	ADFG	sc, co	Yes	1972	ADFG
Starrigavan net pens	Sitka	ADFG	sc, co	Yes	1971	ADFG

[1] ADFG = Alaska Department of Fish and Game, NMFS = National Marine Fisheries Service.
[2] sc = spring chinook salmon, co = coho salmon, sh = steelhead trout, sk = sockeye salmon.
[3] U.S. Fish and Wildlife Service monies.

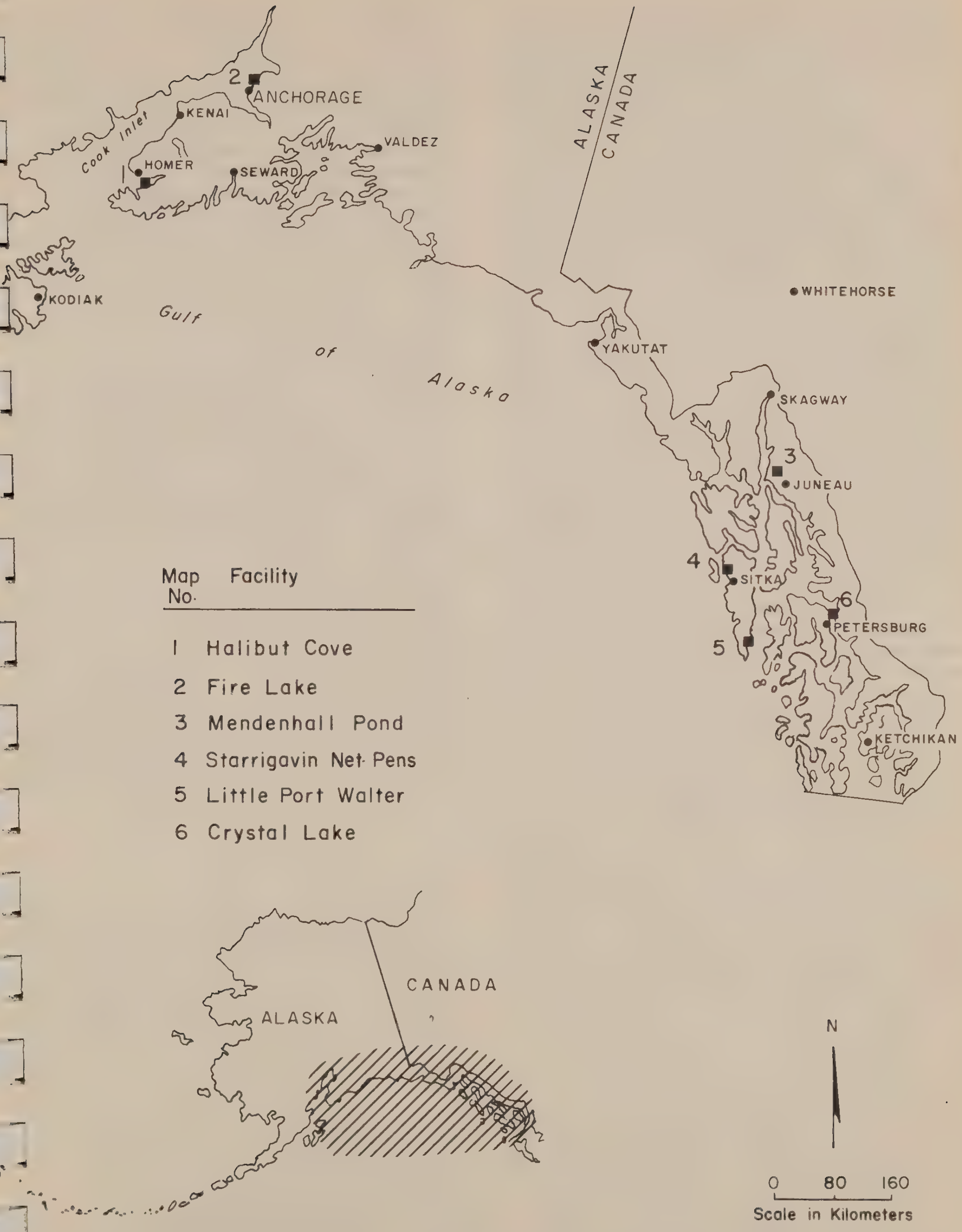
2
ANCHORAGE
KENAI
Cook Inlet
VALDEZ
HOMER
1
SEWARD
KODIAK
Gulf of Alaska
ALASKA
CANADA
WHITEHORSE
YAKUTAT
SKAGWAY
3
JUNEAU
4
SITKA
6
PETERSBURG
5
KETCHIKAN
Map No.
Facility
1 Halibut Cove
2 Fire Lake
3 Mendenhall Pond
4 Starrigavin Net-Pens
5 Little Port Walter
6 Crystal Lake
CANADA
ALASKA
LOCATION MAP
N
0
80
160
Scale in Kilometers

Figure 1.—Map of locations of Alaskan salmonid rearing facilities, 1960-76.

The State legislature also appropriated monies to be used to finance nonprofit, low-interest, State-secured loans for fish culture. The initial facilities built with these funds are still in the developmental stage. Releases made from both these private facilities and the FRED Division incubation stations are not included in this report because they normally consist of unfed fry.

Presently, the two agencies rearing fish in Alaska are concentrating on chinook and coho salmon (Table 4). Since a large majority of the chinook salmon plants have resulted from eggs taken from native stocks which closely approximate the spring race as we have defined it, we have called all of the chinook salmon plants spring chinook.

In 10 yr, releases of migrant chinook salmon went from a meager 400 fish weighing 4 lb (1.8 kg) to almost 600,000 fish weighing 33,000 lb (15,000 kg) in 1974. Coho salmon have also increased, from 171,000 migrants weighing 9,000 lb (4,000 kg) released in 1968 to approximately 1 million migrants weighing 50,000 lb (27,700 kg) in 1974.

Five of the Alaskan rearing facilities presently operating are noteworthy. The first of these, Fire Lake Hatchery, is actually a complex made up of a main hatchery and satellite ponds located at nearby Ft. Richardson and Elmendorf Air Force Base. These ponds are unique as they are the only ones currently using condenser cooling water heated as a byproduct during the thermal generation of electricity. This free supply of warm water allows fish to easily reach migrant size in an area were extreme weather conditions and cold-water temperatures would normally necessitate the use of expensive heating equipment to achieve similar growth.

Little Port Walter is a NMFS Research Station which was established in the late 1930's. It was expanded to include saltwater net pen rearing of coho salmon in the mid-1960's. The net pens are suspended from a floati platform anchored near the shore of a small saltwat bay. The salinities of the net pens are controlled using freshwater piped from nearby Sashin Creek. To obtain the initial supply of coho salmon for rearing, fingerlin were seined from the bay and placed in the pens. Af migrating to the ocean, the adult fish return to the area of the net pens where they are trapped and spawned.

Table 4.—Migrant releases of chinook, coho, and sockeye salmon and steelhead trout—Alaska[1] (in thousands).

Release year	Spring chinook No.	Spring chinook Lb.[2]	Coho No.	Coho Lb.	Sockeye No.	Sockeye Lb.	Winter steelhead No.	Winter steelhead Lb.
1960	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1961	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1962	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1963	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1964	0.4	(3)	0.0	0.0	0.0	0.0	0.0	0.0
1965	8.8	0.3	0.0	0.0	0.0	0.0	0.0	0.0
1966	166.9	1.7	0.0	0.0	0.0	0.0	0.0	0.0
1967	538.3	11.6	0.0	0.0	0.0	0.0	0.0	0.0
1968	82.4	2.8	171.7	8.9	0.0	0.0	0.0	0.0
1969	95.9	5.7	187.4	13.8	0.0	0.0	0.0	0.0
1970	45.7	1.6	227.0	21.5	0.0	0.0	0.0	0.0
1971	217.4	11.6	92.7	6.5	0.0	0.0	0.0	0.0
1972	71.8	3.8	309.7	20.1	0.0	0.0	0.0	0.0
1973	177.3	11.0	143.3	15.9	0.0	0.0	0.0	0.0
1974	598.8	33.3	969.0	50.1	0.0	0.0	0.0	0.0
1975	154.8	6.9	1,032.1	72.1	0.0	0.0	17.5	0.6
1976	225.7	9.7	930.6	48.1	16.2	0.6	16.5	1.4
Total	2,384.2	100.0	4,063.5	257.0	16.2	0.6	34.0	2.0

[1] Derived from Wahle et al. (1975) prior to 1974 and from Alaska Department of Fish and Game and National Marine Fisheries Service release reocrds thereafter.

[2] 1 lb = 0.454 kg.

[3] <100 lb.

The Starrigavan net pens are patterned after the Lit Port Walter facility. They are anchored in the bay ne Sitka. Like its prototype, the facility pipes water from a nearby creek to control salinity. Local and Crystal Lake Hatchery coho salmon fry were initially reared. As th become more available, endemic stocks are replaci those from Crystal Lake.

Halibut Cove is the saltwater net pen facility south west of Anchorage. It is also an offshoot of the Little P Walter and Starrigavan facilities. Rearing salmon in this near Arctic environment is challenging because the lagoon freezes in the winter and the water temperat drops to −2°C (18°F). Freshwater from a nearby lake available only during the warmer months. There are no local salmon stocks available and no hatching facilities on the site, so Fire Lake chinook and coho salmon fry brought in for rearing.

Mendenhall Rearing Pond is located just off the Mendenhall River near Juneau. It is supplied with water from the melting Mendenhall Glacier. This pond is c ered by ice each year from October to May so fish can fed only during the warmer months. During the winter, water under the ice must be aerated with an electric pump. Coho salmon eggs are obtained from returns the rearing pond. Because of the cold water, eggs taken from Mendenhall Pond are transferred to Crystal Lake Hatchery near Petersburg for hatching. The fry are th brought back to the pond for rearing and release.

British Columbia

The program of anadromous fish propagation in British Columbia began in 1884 with the establishment of a hatchery on the Fraser River near the town of New Westminster. From 1901 through the mid-1930's ac tional facilities were constructed and operated by the Provincial government and private fisheries organizations on the Finger and Skeena Rivers, at Rivers In and on Vancouver Island. As in Alaska, all of th hatcheries concentrated on sockeye salmon production, but also intermittently hatched a few chum, coho, chinook, and pink salmon. All fish were released as From 1885 to 1927 more than 2 billion sockeye salr fry were released.

The operation of hatcheries decreased and then finally stopped completely in the late 1930's due to the pression and the outbreak of World War II. Nothing was done on a production basis again until 1967 when a pilot project began at the newly constructed Big Qualicum Hatchery on Vancouver Island. At present, Canad Fisheries and Marine Services (CFMS) operates six facilities in British Columbia (Table 5). Five of these are Vancouver Island and the sixth, Capilano, is on the inland just north of the city of Vancouver (Fig. 2).

Hatchery emphasis has been placed on fall chinook and coho salmon (Table 6) rather than sockeye salmon was the case in the early years. In 9 yr (1968-76) fall nook salmon migrant releases have increased twentyfold (from 147,000 to 30 million fish). Coho salmon releases also increased, from almost 70,000 migrants in 0 to over 2.3 million in 1976. In addition, the CFMS begun a steelhead trout rearing program with the first migrant fish released in 1973 and has been experimenting with summer chinook salmon.

While numbers and pounds released by British Columbia hatcheries each year have been small when compared with the production of the large Columbia River comxes, results have been encouraging. To date, the most matic success has been the survival of the 1971-brood coho salmon released from Capilano hatchery. Of 284,000 fish released, there was a return of 2,700 jacks (fish rening as 2-yr olds) in 1973 and 37,000 adults in 1974. s is a hatchery return of almost 14%. In addition, these fish contributed heavily in the fishery, exhibiting a 1:1 catch to escapement ratio. The total survival for this od of fish was almost 28%.[2]

t is interesting to note that of the six CFMS facilities, three began as spawning channels. All three of these have either been modified to include rearing facilities or have n converted to hatcheries. Big Qualicum Hatchery originally had two spawning channels; one is still being used for that purpose for chum salmon and the other has n converted to a rearing channel. Puntledge and bertson Creek were unsuccessful as spawning channels primarily due to unsuitable water supplied during egg incubation. After several years of operation with poor lts, the two facilities were converted to hatcheries.

Washington Coastal and Puget Sound

The Baker Lake Hatchery built in 1896 by the State of Washington on a tributary of the Skagit River, was the State's first facility located outside the Columbia River system. At this hatchery sockeye salmon were spawned, the eggs hatched, and the fry released back into the Skagit River. After several years, the hatchery was sold to the U.S. Fish Commission and was operated as part of the Federal hatchery system.

Between 1899 and 1925 more than 50 different salmon facilities were constructed and operated in this region by State and Federal agencies. Most were eventually failures due in part to lack of suitable water supplies, an insufficient supply of eggs, lack of funds, or, in many cases, lack of knowledge. A few, such as the Quilcene National Fish Hatchery (1911) operated by the U.S. Fish and Wildlife Service (USFWS) and the Dungeness (1902), Green River (1901), Nooksack (1899), Puyallup Salmon (1917), Samish (1899), Skykomish (1905), and Willapa (1899) hatcheries operated by Washington Department of Fisheries (WDF), are still in operation today.

All species of salmon were reared at these early facilities with coho and fall chinook salmon being predominant at the State hatcheries and fall chinook, coho, and sockeye salmon at the Federal hatcheries. In addition, both State and Federal hatcheries raised steelhead trout. In 1932, responsibility for steelhead and other anadromous trout was transferred to the newly formed Washington Department of Game (WDG) (Berg 1968). The majority of fish from the early State hatcheries were released as unfed fry while the Federal hatcheries reared a considerable number to larger sizes before release.

Due to the serious decline of the fishery resource, WDF, WDG, and USFWS have constructed new facilities to improve the runs of salmon and steelhead trout (Chaney and Perry 1976). Since 1960, these three agencies have operated or supervised a total of 26 hatcheries and 32 rearing ponds or net pens (Table 7). Of these, all of the hatcheries and 19 of the rearing ponds and net pens released anadromous fish in 1976. The rearing facilities in this region are located in two areas: Puget Sound (Fig. 3) and Pacific coast (Fig. 4).

This region has produced a large percentage of the total anadromous salmonids raised on the Pacific coast. The 921 million migrant fish that have been released over the 17 yr since 1960, constitute 27% of the total coastal releases by number (Tables 8, 9). By weight, the 23.4 million lb (10.6 million kg) of migrants are 22% of the coastal total. Migrant releases in 1976 totaled 89.4 mil-

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. Sandercock, Department of Environment, Fisheries and Marine Service, Vancouver 1, B.C., Canada U6E 2P1, pers. commun. November 1976.

Table 5.—Anadromous fish rearing facilities—British Columbia, 1960-76.

Hatcheries	General location	Operation agency[1]	Species reared during year span[2]	Anadromous releases in 1976	Year anadromous operations began
Big Qualicum	Qualicum Beach	CFMS	fc, co, sh	Yes	1967
Capilano River	North Vancouver	CFMS	fc, co, sh	Yes	1971
Puntledge	Courtenay	CFMS	fc	Yes	1971
Quinsam	Campbell River	CFMS	fc, co, sh	Yes	1975
Robertson Creek	Port Alberni	CFMS	fc, co, sh	Yes	1972
Rosewall[3]	Fanny Bay	CFMS	co	Yes	1972

[1] CFMS = Canadian Fisheries and Marine Service.

[2] fc = fall chinook salmon, co = coho salmon, sh = steelhead trout, sc = spring chinook salmon.

[3] Operated as research facility.

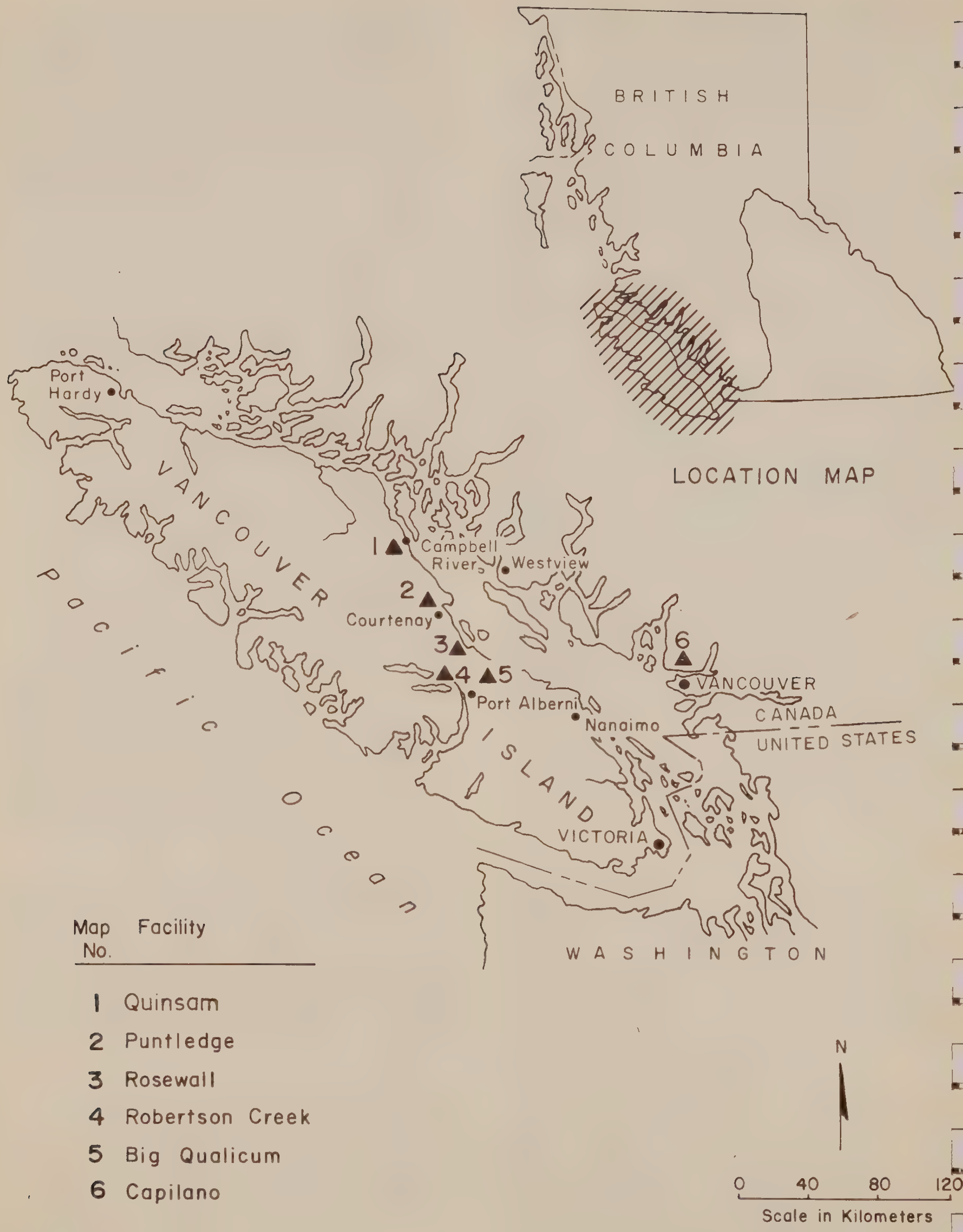
BRITISH COLUMBIA
LOCATION MAP
Port Hardy
VANCOUVER ISLAND
Pacific Ocean
1
Campbell River
Westview
2
Courtenay
3
4
5
Port Alberni
Nanaimo
6
VANCOUVER
CANADA
UNITED STATES
VICTORIA
WASHINGTON
N
0
40
80
120
Scale in Kilometers
Map No.
Facility
1 Quinsam
2 Puntledge
3 Rosewall
4 Robertson Creek
5 Big Qualicum
6 Capilano

Figure 2.—Map of locations of British Columbian salmonid rearing facilities, 1960-76.

Table 6.—Migrant releases of chinook and coho salmon and steelhead trout—British Columbia[1] (in thousands).

lease	Fall chinook		Coho		Winter steelhead	
year	Number	Pounds[2]	Number	Pounds	Number	Pounds
960	0.0	0.0	0.0	0.0	0.0	0.0
961	0.0	0.0	0.0	0.0	0.0	0.0
962	0.0	0.0	0.0	0.0	0.0	0.0
1963	0.0	0.0	0.0	0.0	0.0	0.0
1964	0.0	0.0	0.0	0.0	0.0	0.0
965	0.0	0.0	0.0	0.0	0.0	0.0
966	0.0	0.0	0.0	0.0	0.0	0.0
1967	0.0	0.0	0.0	0.0	0.0	0.0
1968	147.0	1.3	0.0	0.0	0.0	0.0
1969	460.0	4.7	0.0	0.0	0.0	0.0
970	67.5	0.7	69.0	2.5	0.0	0.0
971	299.0	3.0	88.0	2.7	0.0	0.0
1972	822.7	9.0	210.0	7.5	0.0	0.0
1973	2,038.3	23.4	507.6	19.6	41.7	2.0
974	2,361.1	31.7	517.7	20.7	23.0	3.1
975	2,220.1	36.3	998.4	43.8	25.8	2.8
1976	3,005.5	36.8	2,385.7	143.8	80.5	6.3
Total	11,421.2	146.9	4,776.4	240.6	171.0	14.2

[1] Derived from Wahle et al. (1975) prior to 1974 and from Canadian sheries and Marine Service records thereafter.

[2] 1 lb = 0.454 kg.

lion fish and 2.7 million lb (1.2 million kg). In 1976, fall chinook salmon were the most numerous with 35 million released, followed by coho salmon, steelhead trout, and chum salmon. By weight, coho salmon were dominant with 1.3 million lb (0.59 million kg) stocked, followed in order by fall chinook salmon, steelhead trout, and spring chinook salmon. No summer chinook salmon are reared in this region.

As noted in Table 7, the two State fisheries agencies use Dingell-Johnson Act and Anadromous Fish Act monies to partially fund some of their hatchery programs. Dingell-Johnson monies come from a Federal tax on recreational fishing gear and are divided among the States based on the number of fishing licenses sold. It is administered by the U.S. Fish and Wildlife Service (USFWS).

The Anadromous Fish Act (Public Law 89-304) is administered jointly by the USFWS and the National Marine Fisheries Service. Under this Act, cooperative agreements with States are made and other non-Federal interests for the conservation, development, and enhancement of, among others, the anadromous fishery resources of the Nation. Federal matching funds of up to 50% may be used to finance project costs if one state is

Table 7.— Anadromous fish rearing facilities—Washington coastal and Puget Sound, 1960-76.

Facility	General location	Operating agency[1]	Species reared during year span[2]	Anadromous releases in 1976	Year anadromous operation began	Funding agency[1]
Hatcheries						
Aberdeen	Aberdeen	WDG	sh, src	Yes	1936	WDG
rlington	Oso	WDG	sh (src)	Yes	1956	WDG
ellingham	Bellingham	WDG	sh (src)	Yes	1935	WDG
hambers Creek	Tacoma	WDG	sh	Yes	1973	WDG, Anadromous Fish Act[3]
Dungeness	Sequim	WDF	fc, sc, co (ch, pi)	Yes	1902	WDF
eorge Adams	Shelton	WDF	fc, sc, co, ch (pi)	Yes	1960	WDF, Tacoma PUD
reen River	Auburn	WDF	fc, co (sc, ch)	Yes	1901	WDF
Hood Canal	Hoodsport	WDF	fc, sc, co, ch, pi	Yes	1953	WDF
Issaquah	Issaquah	WDF	fc, co (sk)	Yes	1937	WDF
Minter Creek	Purdy	WDF	fc, co, ch (sc, pi, ce)	Yes	1937	WDF
emah	Nemah	WDF	fc, co, ch	Yes	1953	WDF
ooksack	Kendall	WDF	fc, co	Yes	1899	WDF
Puyallup salmon	Orting	WDF	fc, co (sc, pi)	Yes	1917	WDF
Puyallup trout	Puyallup	WDG	sh	Yes	1947	WDG
uilcene	Quilcene	USFWS	fc, co, ch (sh)	Yes	1911	USFWS
uinault	Neilton	USFWS	fc, co, ch, sh	Yes	1968	USFWS
amish	Burlington	WDF	fc, co (ch)	Yes	1899	WDF
Seward Park	Seattle	WDG	sh	Yes	1935	WDG
Shelton	Shelton	WDG	sh, src	Yes	1947	WDG, Anadromous Fish Act[3]
mpson	Matlock	WDF	fc, co (ch)	Yes	1949	WDF, PP&L
Skagit	Marblemount	WDF	fc, sc, co, ch (pi, sh)	Yes	1947	WDF
Skykomish	Startup	WDF	fc, sc, co (ch, pi)	Yes	1905	WDF
Soleduck	Sappho	WDF	fc, sc, co	Yes	1970	WDF
outh Tacoma	Lakewood	WDG	sh	Yes	1933	WDG
okul Creek	Fall City	WDG	sh	Yes	1933	WDG
Willapa	Lebam	WDF	fc, co (ch, sk)	Yes	1899	WDF
Rearing ponds and net pens						
arnaby Pond	Rockport	WDG	sh	Yes	1961	WDG, Dingell-Johnson[3]
ue Slough Pond	Darrington	WDG	sh	No	1961	WDG
Bogachiel Pond	Forks	WDG	sh	Yes	1968	WDG, Anadromous Fish Act[3]
Garrison Creek (Western State)	Steilacoom	WDF	fc, co, pi (sc, ch)	Yes	1973	WDF, Sports Club
reen River pond	Palmer	WDG	sh	Yes	1968	WDG, Anadromous Fish Act[3]

Table 7.—Continued.

Facility	General location	Operating agency[1]	Species reared during year span[2]	Anadromous releases in 1976	Year anadromous operation began	Funding agency[1]
Harrison	Rockport	WDG	sh	No	1970	WDF, Dingell-Johnso
Mayr Bros. pond	Aberdeen	WDG, Private	sh	Yes	1974	WDG, Private
Olympic rearing channel	Port Angeles	WDF	fc, co	Yes	1975	WDF
Percival-Deschutes Complex (including Capital Lake)	Olympia	WDF	fc, sc, co	Yes	1949	WDF, Olympic Salmon Club
Salt Creek pond	Joyce	WDG	sh	No	1964	WDG, Sportsmen's Group
Skykomish ponds	Gold Bar	WDG	sh	Yes	1974	WDG
South Sound net pens	Tacoma	WDF	fc, co, ch	Yes	1972	WDF
Squaxin	Squaxin Island	WDF, Squaxin Tribe	fc, sc, co	Yes	1971	WDF, Squaxin Tribe
Tualip	Marysville	WDF, Tualip Tribe	fc, co	Yes	1973	WDF, Tualip Tribe
Whitehorse	Darrington	WDG	sh (src)	Yes	1962	WDG, Dingell-Johnson[3]
WDF minor facilities and coops						
Bay Center	Bay Center	Bay Center Mariculture	fc, ch, pi	No	1972	Private
Bowmans Bay	Anacortes	WDF	fc, sc, co, ch	No	1947	WDF
Domsea Farms	Manchester	Domsea Farms Mariculture	co	No	1969	Domsea Farms Mariculture
Elliot Pond	Seattle	WDF, NW Steelheaders	fc, co	No	1974	WDF, NW Steelhead
Gig Harbor net pens	Gig Harbor	WDF, Puget Sound Herring Sales, Peninsula High Key Club	fc, ch	Yes	1975	WDF, Puget Sound herring sales
Gorst Creek	Bremerton	WDF, Sports Club	fc	No	1962	WDF
Little Clam Bay	Port Orchard	WDF	co	No	1962	WDF
Lummi	Bellingham	Lummi Tribe	co	Yes	1972	Lummi Tribe
Manchester	Port Orchard	WDF	fc, co	No	1973	WDF
NW Steelheaders	Palmer, Renton	WDF, NW Steelheaders	sc, co	No	1971	WDF, NW Steelhead
Ocean Shores pond	Ocean Shores	Sports Group	co	Yes	1974	Sports Group
Peninsula	Port Angeles	Peninsula Jr. College	co	Yes	1975	Peninsula Jr. College
Sultan Pond	Sultan	WDF, Sultan Sportsmen's Club	co	Yes	1973	Sultan Sportsmen's Club
Tacoma net pens (including Totem Marina)	Tacoma	WDF, City of Tacoma	fc, co	Yes	1973	WDF, City of Tacoma
Westport boat basin	Westport	WDF, Ocosta School	co	Yes	1972	WDF
Whidby Island	Oak Harbor	WDF, Sports Club	fc, sc, co	No	1972	WDF, Sports Club
Wynoochee Pond	Montesano	WDF, NW Steelheaders	fc, co	No	1974	WDF, NW Steelheaders

[1] WDG = Washington Department of Game, WDF = Washington Department of Fisheries, Tacoma PUD = Tacoma Public Utility District, USF = U.S. Fish and Wildlife Service, PP&L = Pacific Power and Light.

[2] fc = fall chinook salmon, sc = spring chinook salmon, co = coho salmon, sh = steelhead trout, ch = chum salmon, pi = pink salmon, ce = cherry salmon, src = sea-run cutthroat trout, sk = sockeye salmon (minor species in parentheses).

[3] Dingell-Johnson Act monies administered by U.S. Fish and Wildlife Service, Anadromous Fish Act monies administered by National Ma Fisheries Service and U.S. Fish and Wildlife Service.

involved. If two states cooperate on a project, the matching funds can total 66 2/3%.[3]

State and Federal anadromous salmonid rearing programs in this region are augmented by: 1) State and private cooperative efforts, 2) commercial enterprises, 3) regulated Indian tribe rearing programs, and 4) unregulated Indian tribe rearing programs.

The WDF cooperates with sport and school groups in salmon rearing programs. The agency supplies surplus fry for rearing in saltwater net pens or ponds. The cooperating groups supply equipment, fish food, and lal needed to rear the fish to migrant size. Releases are ma directly from the pens or ponds. Facilities operated in this manner include Northwest Steelheader (various Puget Sound areas), Gorst Creek, Percival, Salt Cre Whidby Island, and Westport boat basin.

Two commercial fish rearing companies, Domsea Farms and Bay Center Mariculture, have released sal on in this region. Normally these companies buy surp eggs from State hatcheries, rear the fish to smolt size freshwater, and then transfer the fish to saltwater net pens for final rearing to market size. Although empha is placed on commercial production, cooperative expe mental releases have been made. Under Washington law, the companies have no special harvest rights to fish turning to the release site.[4]

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[3] E. Wold, Director, Columbia River Fisheries Development Program, National Marine Fisheries Service, NOAA, Portland, OR 97208, pers. commun. June 1979.

While the private companies are prohibited by State law from engaging in "ocean ranching," (see Oregon Coastal section), the treaty Indian tribes are not. Many bal councils have become active in this form of aqua-lture. The operations take place either on streams completely within reservation boundaries or on streams where the tribe has been granted exempt status through eaty. In one example of this type of operation, the inault Indians, as a tribal enterprise, hatch and rear salmon and release them into the Quinault River system. fter maturing in the ocean, adult fish return to the uinault River where many are caught in the exclusively Indian river net fishery.[5]

The fish released by these Indian operated facilities do ntribute to ocean sports and commercial catches fore they return to the rivers where only tribal members may fish for them. Because of difficulties in obtaining accurate release information from some of the erations, we have included in this report only the re-ses from facilities that provide information to WDF.

Columbia Basin

The Columbia Basin, as referred to in this report, contains the portions of Washington, Idaho, and Oregon ained by the Columbia River (Fig. 5). The five State d Federal fish management agencies in this region account for 54% (by number) and 55% (by weight) of the total Pacific coast anadromous releases made in 1976 ables 10, 11). Migrant releases for the 17-yr period rting in 1960 amount to over 2 billion fish and 61 million lb (27.7 million kg), raised at a total of 81 facilities—63 hatcheries and 18 rearing ponds. During the 17- all species of fish included in this report, except pink mon, were released into streams of the basin. During 1976, anadromous migrants were released from 53 hatcheries and 14 rearing ponds.

The Columbia Basin is unique in the number of hatcheries constructed and operated as compensation for habitat destroyed by water use projects on the Columbia ver and its tributaries. Compensation was initiated on Columbia River by the Mitchell Act passed by Congress in 1938. The Act provided for a cooperative fisheries management program involving the Federal vernment and the States of Oregon and Washington. ially a small amount of money was appropriated for the implementation of the Act under the Department of Commerce. Little was accomplished until 1946 when the was amended to create the Lower Columbia River elopment Program (subsequently referred to as the Program) at the time under the Department of Interior. Initial funding came from the U.S. Army Corps of gineers and the Program was administered by the USFWS. The funds were used for stream clearance and construction and modernization of hatcheries.

In 1956, the Program was expanded to include the upper Columbia and Snake River drainages extending into Idaho. The word "Lower" was subsequently dropped from the Program name. The funding is now administered by the National Marine Fisheries Service, Department of Commerce, Portland, Oreg.

Since 1960, releases from Program hatcheries have accounted for 74% of the Columbia Basin migrant release by number and 57% by weight (Tables 12, 13).

In recent years, an additional source of funds for construction and operation of hatcheries in the basin has been the power producing agencies and companies. The U.S. Army Corps of Engineers has funded the construction or modernization of nine hatcheries as mitigation and compensation for their hydroelectric projects and is presently providing operational monies for these facilities. Also in the basin, 17 facilities were constructed by public utility districts or private power companies in connection with the effects of their water related projects.

Columbia Basin-Washington.—The State Fish Commissioner, James Crawford (1890), stated in his first report to the Governor of Washington concerning artificial propagation: "To foster and replenish the streams of our state with salmon and trout, the establishment of a hatchery is a positive necessity. While though much could be done by the passage and enforcement of a stringent law protecting our fish during the spawning season, still, as has been demonstrated in the older states without the aid of artificial propagation, the stock of wild fish will eventually be exhausted." This statement was based on declining populations of fish in Washington's rivers, especially the Columbia, even at that early date. Diversions and obstructions were blocking access to historically important spawning and rearing areas. Also, operators of gill nets, fish wheels, and traps, along with the Indians and their dip nets, were taking excessive numbers of fish. It was estimated that each fish wheel took more than 100 tons of fish per year (Crawford 1890). The pack of salmon by Washington canneries had increased from 4,000 cases in 1866 to a high of 629,000 cases in 1883 (Crawford 1892) and then declined to 321,000 cases in 1889 (Cobb 1931).

In light of this dwindling resource, the 1891 legislature appropriated $15,000 for securing a site and erecting a hatchery. The commission first selected a location in Okanogan County, but was unable to build there because of title and land survey problems (Crawford 1892).

In 1894, Commissioner Crawford investigated the possibility of enhancing upper Columbia stocks of salmon by taking and eyeing eggs artificially in the lower reaches of the Columbia River and transporting them to suitable hatching sites up the river. Working with fishermen using pound net traps in Baker's Bay, near the mouth of the Columbia River, he secured 150 chinook salmon which he held for spawning. He obtained only 6,000 eggs before the holding area was washed out. No

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. Senn, Chief of Artificial Production, Washington Department of eries, Olympia, WA 98504, pers. commun. November 1977.

. Mahnken, Manchester Field Station, National Marine Fisheries Service, NOAA, Manchester, WA 98353, pers. commun. August 1976.

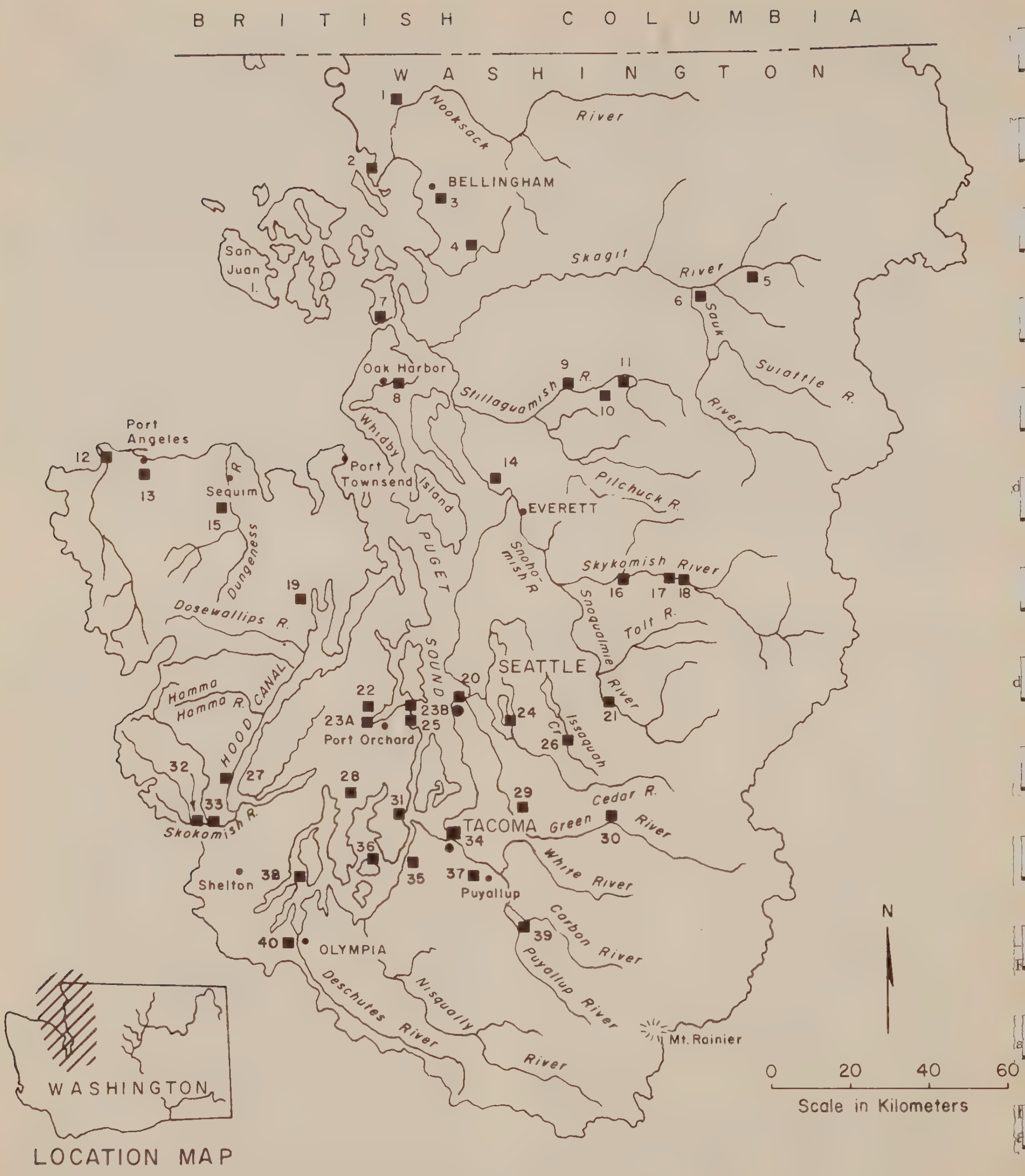
BRITISH COLUMBIA
WASHINGTON
Nooksack River
BELLINGHAM
San Juan I.
Skagit River
Sauk
Suiattle R.
River
Oak Harbor
Stillaguamish R.
Whidby Island
Port Angeles
Port Townsend
Sequim
R.
Dungeness
Dosewallips R.
EVERETT
Pilchuck R.
Snohomish R.
Skykomish River
PUGET SOUND
Snoqualmie River
Tolt R.
SEATTLE
Hamma Hamma R.
HOOD CANAL
Port Orchard
Issaquah Cr.
Cedar R.
River
Skokomish R.
TACOMA
Green River
White River
Shelton
Puyallup
Carbon River
OLYMPIA
Deschutes River
Nisqually River
Puyallup River
Mt. Rainier
N
0 20 40 60
Scale in Kilometers
WASHINGTON
LOCATION MAP
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23A 23B 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40

Figure 3.—Map of locations of Washington-Puget Sound salmonid rearing facilities, 1960-76.

further efforts to take eggs were made that year, but the idea was proven feasible as the eggs survived the transfer (Crawford 1896).

A law passed in 1893 provided for licensing of all Washington commercial fishermen. The fishermen supported the measure. The monies were to be placed in the Fish Commission fund to be used for fishery projects. In 1895, $20,000 was appropriated from this fund and the first hatchery in Washington was built on the Kalama River, 4 mi above its junction with the Columbia Riv The land was donated by the citizens of Cowlitz Coun Its initial capacity, 4 million eggs, was increased to 6 million in 1896. An auxiliary station was built on the Chinook River near the mouth of the Columbia River collecting eggs as well as for hatching additional f (Crawford 1896).

Map No	Facility	Map No	Facility
	oksack	23A	Domsea Farms-Freshwater
	mmi Ponds and Net Pens	23B	Domsea Farms—Saltwater
3	llingham	24	Seward Park
4	Samish	25	Little Clam Bay
5	Skagit		Manchester
	rrison Pond	26	Issaquah
	rnaby Pond	27	Hood Canal
7	Bowmans Bay	28	Minter Creek
8	Whidbey Island Rearing Pond	29	Green River Hatchery
	lington	30	Green River Pond
	ue Slough	31	Gig Harbor
	hitehorse	32	Shelton
12	Olympic Rearing Channel	33	George Adams
13	Peninsula College	34	Totem Marine (Tacoma Net Pens)
	lalip	35	South Tacoma
	ngeness		Garrison Creek
16	Sultan Pond		Chambers Creek
17	Skykomish Hatchery	36	South Sound Net Pens
	ykomish Rearing Ponds	37	Puyallup Trout
	ilcene	38	Squaxin Island Net Pens
	liot Bay Net Pens	39	Puyallup Salmon
21	Tokul Creek Hatchery and Pond	40	Percival-Deschutes Complex
22	Gorst Creek Pond		(including Capital Lake)

Not Shown - Misc Northwest Steelheaders Net Pens

By 1900, State hatcheries were being constructed on Wenatchee, Wind, Little Spokane, Methow, and kitat Rivers (Berg 1968). In addition, the U.S. Fish Commission constructed a station on the Little White Salmon River in 1897, supplemented by an auxiliary sta- on the Big White Salmon River. All these early hatcheries concentrated their efforts on chinook salmon fry plants. Coho salmon fry and chinook salmon finger- releases became more prevalent after 1900, especial- the Federal facilities. In addition, some steelhead trout and chum salmon fry were also produced. In 1932, the Washington State legislature divided the anadro- s fish programs between two newly created agencies. Washington Department of Fisheries (WDF) assumed responsibility for salmon and the Washington Department of Game (WDG) became responsible for trout lhead and sea-run cutthroat).

e program of artificial propagation in Washington continued at about the same level until the early 1940's when the Columbia River Development Program (see mbia Basin section) became active in this area. Under the Program, fish ladders were built over impassible barriers and log jams were removed from such mbia River tributaries as Abernathy Creek and the ma, Cowlitz, Wind, and Klickitat Rivers to open up new spawning areas that were previously blocked to migrating fish. New hatcheries including Willard National Hatchery (NFH), Klickitat, and Skamania were tructed, and Spring Creek NFH, Little White NFH, and Carson NFH remodeled.

From 1960 to 1976, 30 hatcheries and 12 rearing ponds d anadromous salmonids in this region (Table 14). 76, the USFWS operated 3 hatcheries and 2 hatchery complexes, WDF operated 10 hatcheries and 5 ponds, and WDG operated 11 hatcheries and 4 ponds. The two WS hatchery complexes, Little White Salmon NFH Leavenworth NFH, were formed in 1976 by placing one and two formerly independent stations (Willard, and Winthrop and Entiat, respectively) under the managers of these two complexes. Although the facilities in this region are scattered throughout the Columbia River drainage, there is a large concentration in the lower river and its tributaries within 75 mi of Portland, Oreg. (Fig. 6).

This region, with 1.2 billion migrant releases between 1960 and 1976, is the largest producer of salmon and steelhead trout on the coast. In 1976 releases numbered 92.6 million smolts, 31% of the coastal total, weighing 3.4 million lb (1.5 million kg), 31% of the total (Tables 15, 16).

Columbia Basin-Idaho.—Artificial production of salmon and steelhead in Idaho began around the turn of the century. A substation of Clackamas Hatchery, operated in Oregon by the U.S. Commission of Fish and Fisheries, was constructed on the Salmon River to take salmon and steelhead eggs. Additionally, eggs were shipped into the State from Clackamas Hatchery and another of its substations, Little White Salmon Hatchery, located in Washington. Fry hatched were released to the Pahsimeroi and Lemhi Rivers as well as the Salmon River (Leach 1932, 1933). This substation was phased out during the mid-1930's when the Federal hatchery system underwent a drastic budget reduction.

In addition to the Federal hatchery, the State of Idaho included a few salmon and steelhead with trout programs of their early hatcheries. In one example, the State took eggs from brood steelhead trout trapped in the Lewiston Dam fish ladder, eyed them in a spring at Hatwai Creek, and reared them at Grangeville Hatchery.[6]

All of the early hatchery efforts were minor in scope. The State relied instead on wild stocks of fish to perpetuate the anadromous fish runs. In 1956, because of the decline in the stocks, the Columbia River Development Program extended to the upper Columbia and Snake Rivers. (See the Columbia Basin section.) Under the Program, natural spawning and rearing areas were increased in Idaho through, among others, the construction of fishways over Sellway Falls and the now removed Lewiston Dam in the Clearwater River drainage and Dagger Falls on the Middle Fork Salmon River. Approximately 220 screens were built on irrigation diversions to prevent the loss of fish onto irrigated fields. Obstructions and debris were also removed from tributaries of the Clearwater River.

It had become obvious by 1960 that the increase in the number of dams in the Columbia and Snake Rivers had caused upstream passage problems for adult fish and downstream mortality for juvenile fish. About this time, Idaho Power Company was required to construct fish rearing facilities below Oxbow Dam on the Snake River, and more attention was focused on rearing anadromous fish in Idaho's hatcheries (Chaney and Perry 1976).

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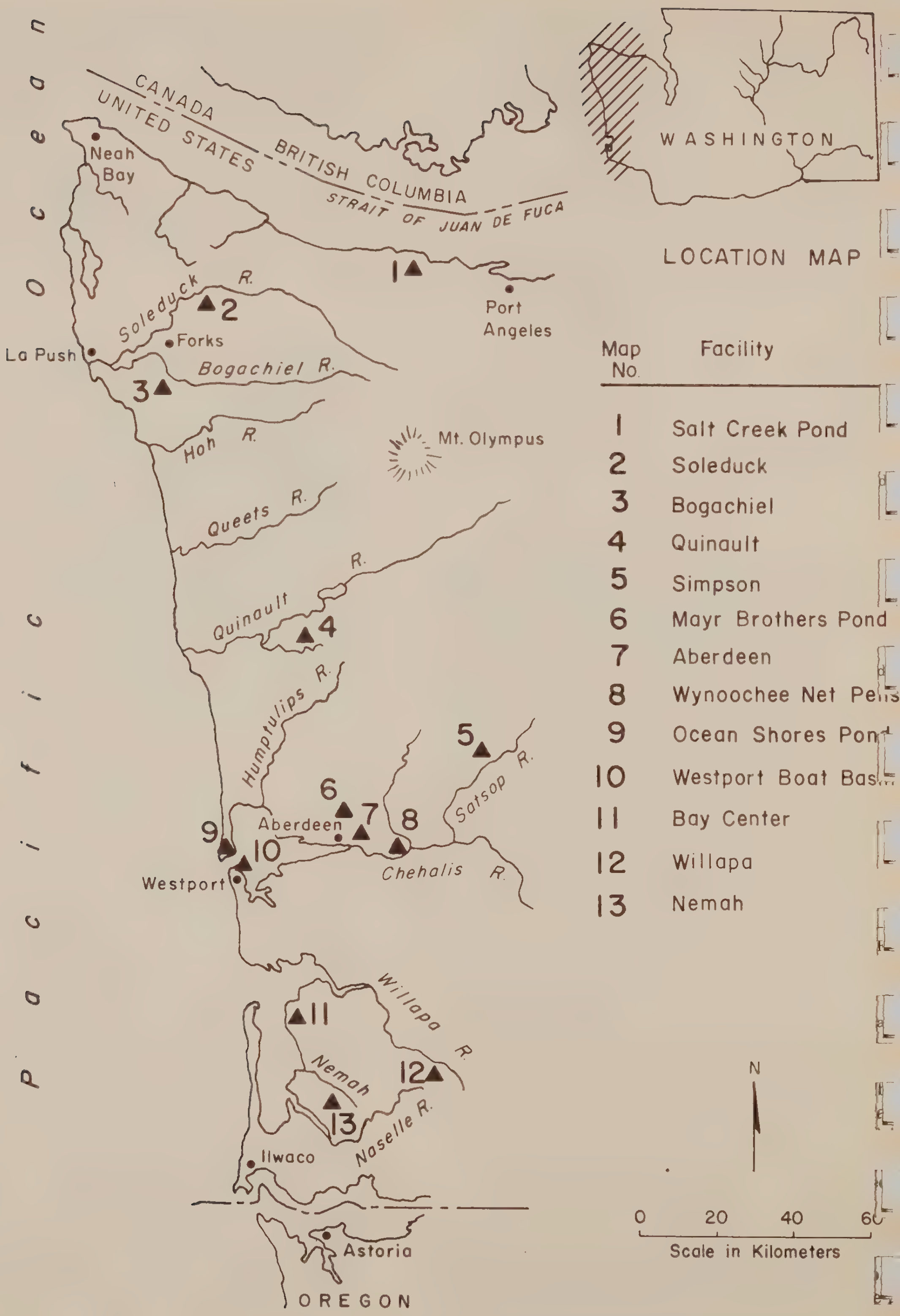
[6] D. Ortmann, Idaho Department of Fish and Game, Boise, ID 83707, pers. commun. September 1976.


Pacific Ocean
CANADA
UNITED STATES
BRITISH COLUMBIA
STRAIT OF JUAN DE FUCA
Neah Bay
La Push
Forks
Port Angeles
Soleduck R.
Bogachiel R.
Hoh R.
Mt. Olympus
Queets R.
Quinault R.
Humptulips R.
Satsop R.
Chehalis R.
Aberdeen
Westport
Willapa R.
Nemah
Naselle R.
Ilwaco
Astoria
OREGON
1
2
3
4
5
6
7
8
9
10
11
12
13
WASHINGTON
LOCATION MAP
N
0
20
40
60
Scale in Kilometers

Map No.	Facility
1	Salt Creek Pond
2	Soleduck
3	Bogachiel
4	Quinault
5	Simpson
6	Mayr Brothers Pond
7	Aberdeen
8	Wynoochee Net Pens
9	Ocean Shores Pond
10	Westport Boat Bas
11	Bay Center
12	Willapa
13	Nemah

Figure 4.—Map of locations of Washington coastal salmonid rearing facilities, 1960-76.

Table 8.—Migrant releases of chinook and coho salmon and steelhead trout—Washington coastal and Puget Sound[1] (in thousands).

Release year	Fall chinook		Spring chinook		Coho		Winter steelhead		Summer steelhead	
	Number	Pounds[2]	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
1960	20,065.3	89.0	302.4	7.5	6,094.2	126.5	1,128.2	156.3	0.0	0.0
1961	19,508.0	123.9	694.7	10.6	9,612.6	243.5	847.0	135.6	20.4	1.7
1962	20,914.1	112.0	584.6	12.6	9,541.6	185.1	1,215.3	168.9	0.0	0.0
1963	19,224.1	114.1	466.3	7.1	5,297.8	96.7	1,236.0	165.4	206.6	21.4
1964	29,380.5	185.9	294.8	16.9	9,687.2	305.1	1,205.2	175.9	121.6	13.0
1965	30,955.2	196.5	491.8	15.5	10,763.3	358.1	1,204.5	177.5	132.2	13.8
1966	27,566.0	212.8	62.8	4.6	12,907.0	500.5	1,380.2	205.1	97.0	12.6
1967	29,938.7	238.3	378.5	32.7	12,787.3	634.0	1,152.9	179.0	77.3	9.2
1968	30,163.1	290.7	558.9	45.3	13,855.3	721.5	1,305.2	186.6	193.0	22.7
1969	36,030.0	320.0	256.8	21.4	14,901.0	779.8	1,960.0	278.0	124.9	17.7
1970	31,745.1	290.1	309.4	17.7	18,297.2	940.8	1,606.6	256.8	325.4	37.0
1971	47,330.8	434.2	190.1	24.0	16,497.0	928.8	1,581.0	227.4	364.7	62.9
1972	36,221.1	418.8	708.2	48.5	18,969.7	1,083.2	1,454.7	257.0	392.6	63.5
1973	43,007.7	635.2	1,267.0	170.4	18,425.3	1,049.7	1,796.1	321.2	421.7	62.4
1974	31,004.3	688.0	829.5	96.0	21,270.0	1,313.7	1,533.1	283.2	528.4	67.9
1975	33,342.7	702.1	1,030.3	164.4	22,858.7	1,263.6	1,582.4	288.7	564.4	75.3
1976	34,902.5	759.0	693.6	118.5	23,539.4	1,255.4	2,296.5	389.9	399.9	58.8
Total	521,299.2	5,810.6	9,119.7	813.7	245,304.6	11,786.0	24,484.9	3,852.5	3,970.1	539.9

[1] Derived from Wahle et al. (1975) prior to 1974, Foster et al. (Foster, R., R. Kolb, and V. Fletcher. 1975. 1974 hatchery statistical report of production and plantings. Wash. Dep. Fish., Olympia, 156 p.) for WDF 1974, Fletcher et al. (Fletcher, V., B. Kiser, B. Rogers, and B. Foster. 1976. 1975 hatchery statistical report of production and planting. Wash. Dep. Fish., Olympia, 154 p.) for WDF 1975, Foster et al. (1977) for WDF 1976, and from WDG release records and USFWS hatchery annual reports.

[2] 1 lb = 0.454 kg.

Table 9.—Migrant releases of chum, pink, sockeye, and cherry salmon and sea-run cutthroat trout—Washington coastal and Puget Sound[1] (in thousands).

Release year	Chum		Pink		Sockeye		Cherry		Sea-run cutthroat	
	Number	Pounds[2]	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
1960	5,031.6	8.8	555.5	2.5	0.0	0.0	0.0	0.0	0.0	0.0
1961	4,710.5	12.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1962	1,141.8	2.8	145.7	0.5	0.0	0.0	0.0	0.0	0.0	0.0
1963	3,683.6	6.8	0.0	0.0	4.4	([3])	0.0	0.0	0.0	0.0
1964	3,207.7	6.7	525.3	0.9	0.0	0.0	0.0	0.0	0.0	0.0
1965	2,911.4	5.5	0.0	0.0	0.0	0.0	0.0	0.0	24.0	1.5
1966	1,047.3	3.6	421.0	1.3	0.0	0.0	0.0	0.0	134.7	24.1
1967	1,302.9	3.4	0.0	0.0	0.0	0.0	0.0	0.0	156.6	20.3
1968	1,090.7	3.1	602.8	1.4	0.0	0.0	0.0	0.0	155.4	22.3
1969	2,318.1	5.5	0.0	0.0	0.0	0.0	0.0	0.0	136.3	29.2
1970	1,500.5	4.3	774.9	2.4	0.0	0.0	0.0	0.0	85.2	16.1
1971	3,839.6	9.0	0.0	0.0	0.0	0.0	0.0	0.0	251.5	48.3
1972	4,985.7	16.0	1,957.9	5.1	2.5	([3])	0.0	0.0	111.8	26.3
1973	6,001.9	19.1	0.0	0.0	0.0	0.0	24.3	3.1	130.0	31.7
1974	9,384.8	30.7	1,211.9	3.5	0.0	0.0	44.4	4.3	107.7	19.3
1975	29,637.5	88.2	0.0	0.0	0.0	0.0	1.0	0.1	96.0	22.0
1976	22,653.1	81.9	4,850.4	8.7	0.0	0.0	0.5	0.1	79.8	21.2
Total	104,448.7	308.0	11,045.4	26.3	6.9	([3])	70.2	7.6	1,469.0	282.3

[1] Derived from Wahle et al. (1975) prior to 1974, Foster et al. (see footnote 1, Table 8) for WDF 1974, Fletcher et al. (see footnote 1, Table 8) for WDF 1975, Foster et al. (1977) for WDF 1976, and from WDG release records and USFWS hatchery annual reports.

[2] 1 lb = 0.454 kg.

[3] <100 lb.

1976, releases had been made from two USFWS hatcheries and 11 hatcheries and 1 rearing pond operated by the Idaho Department of Fish and Game (IDFG) le 17). Of these, two are especially notable. Dwor- NFH was constructed at a cost of over $16 million by the U.S. Army Corps of Engineers. It was built as pensation for the loss of a large run of steelhead trout ff by the construction of Dworshak Dam. It is one of the largest and most modern of the Pacific coast facilities. The State's Rapid River Hatchery (funded by Idaho Power Company) has been very successful as a spring chinook salmon station. From initial return of 1,039 immature male fish (jacks) in 1968, the run has grown until in 1973 the total number of returning fish reached a high in excess of 17,000.

Of the 14 facilities, only the 6 on the Clearwater and Salmon River drainages are directly accessible to returning fish (Fig. 7). The remainder are above the limits for

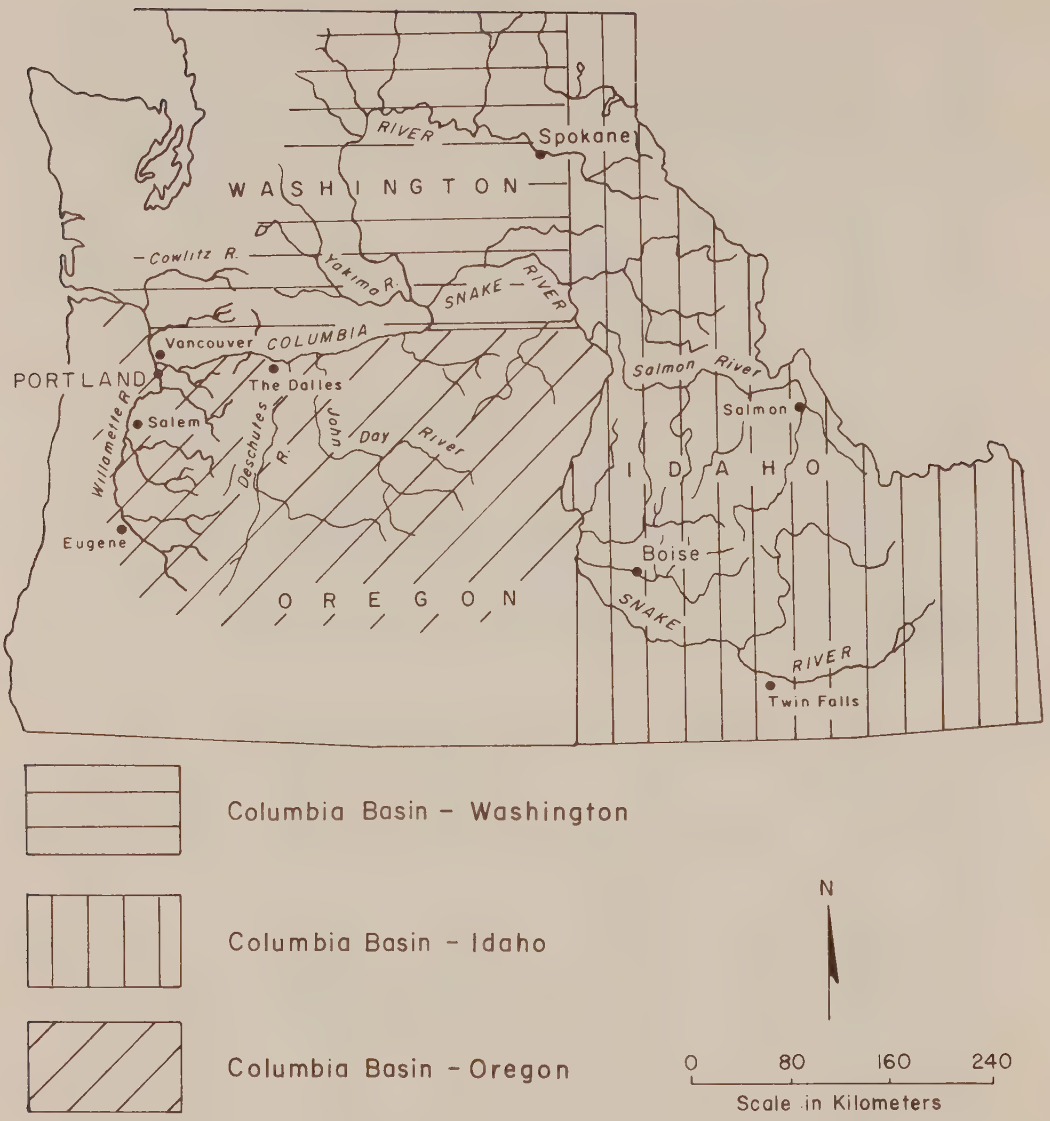

RIVER
Spokane
WASHINGTON
Cowlitz R.
Yakima R.
SNAKE RIVER
Vancouver
COLUMBIA
PORTLAND
The Dalles
Salem
Willamette R.
Deschutes R.
John Day River
Eugene
OREGON
Salmon River
Salmon
IDAHO
Boise
SNAKE
RIVER
Twin Falls
Columbia Basin - Washington
Columbia Basin - Idaho
Columbia Basin - Oregon
N
0
80
160
240
Scale in Kilometers

Figure 5.—Columbia Basin regions.

salmon and steelhead trout migration. In these cases, the State has been very successful with the program of transferring fish reared to suitable release sites, and trapping and returning brood stock, spawning them, and transporting the eggs back to the hatchery. In this way, IDFG has been able to make good use of off-site hatcheries on good water sources.

Summer steelhead trout and spring chinook salmon are the two species reared in the greatest numbers in Idaho. Although the facilities in the State have released only 6% of the Pacific coast migrant totals by weight since 1960, they have accounted for 42% of the summer steelhead trout and 11% of the spring chinook salmon by weight during that period (Table 18). Summer steelhead trout production has increased from an initial release in 1965 of 24,000 migrant fish weighing 2,600 lb (1,200 kg) to a high of 6.3 million fish weighing 750,000 lb (340,200 kg in 1974. This is largely due to the opening of Dworshak NFH in 1969.

Columbia Basin-Oregon.—The first hatchery in Oregon was constructed by a private corporation, the Ore gon and Washington Fish Propagating Company hatchery, the first in the Columbia Basin, was bu in 1876 on the Clackamas River near its confluence with the Willamette River. The company operated the hatc from 1876 to 1880 when lack of funds forced a closu 1887, the Oregon Fish and Game Commission rented and renovated the facility, but was able to operate it for only 1 yr because of funding problems. In 1889, the oper of the hatchery was transferred to the U.S. Commi of Fish and Fisheries. One condition of this transfer wa

Table 10.—Migrant releases of chinook and coho salmon and steelhead trout—Columbia Basin[1] (in thousands).

Release year	Fall chinook		Spring chinook		Summer chinook		Coho		Winter steelhead		Summer steelhead	
	Number	Pounds[2]	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
1960	91,923.9	341.1	7,235.5	207.4	0.0	0.0	7,394.8	249.8	933.9	125.8	153.8	22.5
1961	49,269.2	319.6	4,483.3	171.7	0.0	0.0	15,088.2	526.0	894.2	100.5	480.7	64.1
1962	57,573.4	290.7	4,854.4	190.0	0.0	0.0	14,617.1	610.9	1,812.4	169.8	355.5	41.1
1963	60,043.0	331.8	8,742.4	327.3	0.0	0.0	22,416.9	811.2	1,314.9	120.3	837.6	101.6
1964	66,782.5	415.6	13,037.7	432.9	0.0	0.0	18,128.4	838.8	1,342.6	173.6	1,328.0	180.0
1965	58,355.8	381.4	6,387.2	251.3	0.0	0.0	20,713.8	947.9	1,701.9	227.0	1,259.8	144.4
1966	56,324.2	498.1	11,277.4	455.9	0.0	0.0	24,663.0	1,205.8	1,733.1	206.5	1,467.3	188.1
1967	57,808.3	512.9	12,881.6	560.4	0.0	0.0	23,791.9	1,181.2	1,997.7	234.7	2,940.0	348.1
1968	65,360.3	677.2	12,448.2	734.0	2,138.3	13.6	19,294.4	1,064.8	1,773.1	200.5	4,329.4	503.8
1969	68,593.1	686.3	9,190.4	692.7	2,121.3	20.2	28,043.6	1,661.9	1,665.6	197.0	4,212.0	502.9
1970	86,255.7	902.6	15,986.0	1,387.9	4,228.2	35.4	25,160.8	1,474.3	2,112.4	299.0	5,921.8	911.5
1971	84,414.2	697.3	13,336.2	991.1	2,184.5	37.0	29,424.2	1,728.2	2,241.1	257.6	7,187.5	935.6
1972	90,689.5	993.4	15,140.3	1,267.0	2,604.9	42.6	34,176.7	2,264.5	2,073.5	267.6	5,334.5	836.6
1973	93,619.3	1,122.7	15,243.9	1,450.8	2,312.6	34.3	29,235.5	1,747.8	2,640.3	392.2	7,207.3	824.7
1974	91,303.9	1,203.9	14,060.4	1,093.3	1,202.8	43.0	28,733.7	1,740.7	2,236.0	294.7	8,956.5	1,117.2
1975	92,382.6	1,239.6	19,243.5	1,538.1	120.8	3.1	30,079.6	2,016.2	1,949.4	279.8	6,177.2	915.5
1976	98,855.7	1,342.5	20,236.9	1,672.5	880.5	42.7	29,808.3	1,823.4	2,274.4	340.0	6,247.6	910.5
Total	1,269,554.6	11,956.7	203,785.3	13,424.3	17,793.9	271.9	400,770.9	21,893.4	30,696.5	3,886.6	64,396.5	8,548.2

[1] Derived from Wahle et al. (1975) prior to 1974 and from appropriate State and Federal agencies thereafter.

[2] 1 lb = 0.454 kg.

Table 11.—Migrant releases of chum, sockeye, and cherry salmon and sea-run cutthroat trout—Columbia Basin[1] (in thousands).

Release year	Chum		Sockeye		Cherry		Sea-run cutthroat	
	No.	Lb.[2]	No.	Lb.	No.	Lb.	No.	Lb.
0	0.0	0.0	3,177.0	69.2	0.0	0.0	1.2	1.3
1	63.6	0.4	2,788.0	72.5	0.0	0.0	15.9	2.6
1962	717.5	1.8	2,224.0	43.8	0.0	0.0	9.7	3.1
1963	1,770.8	2.5	3,121.0	67.8	0.0	0.0	12.9	2.7
4	150.8	0.2	3,364.0	58.8	0.0	0.0	82.5	10.0
5	205.3	0.3	3,301.0	73.6	0.0	0.0	86.9	13.9
6	738.1	2.4	73.0	1.6	0.0	0.0	87.0	17.5
1967	524.1	3.0	0.0	0.0	0.0	0.0	190.0	40.9
1968	173.6	0.6	0.0	0.0	0.0	0.0	248.2	52.5
9	129.9	0.3	23.4	0.7	0.0	0.0	261.3	50.3
0	62.5	0.1	0.0	0.0	0.0	0.0	303.5	59.1
1971	0.0	0.0	0.0	0.0	0.0	0.0	371.3	66.9
1972	638.5	1.2	0.0	0.0	0.0	0.0	172.9	40.6
3	563.6	1.4	0.0	0.0	1.8	0.1	210.9	48.7
4	627.3	3.4	0.0	0.0	0.0	0.0	150.3	31.9
5	0.0	0.0	0.0	0.0	0.0	0.0	173.7	43.9
1976	1,126.8	4.7	0.0	0.0	0.0	0.0	192.7	45.9
Total	7,492.4	22.3	18,071.4	388.0	1.8	0.1	2,570.9	531.8

erived from Wahle et al. (1975) prior to 1974 and from appropriate e and Federal agencies thereafter.

[2] 1 lb = 0.454 kg.

t no eggs or fry obtained were to be taken out of gon.

Around the turn of the century, several other hatcheries and egg taking stations were built on the Clackamas er by government and private organizations. Due to ncial difficulties, ownership of these often changed hands, and most were operated by the Federal Government for at least part of their existence. One, built by the umbia River Packer's Propagating Company on the er Clackamas River, was operated privately in 1895-96, Federally in 1897-98, and finally by the State in 1899.

Propagation of steelhead trout in the State began in 7. The U.S. Commission of Fish and Fisheries had success with a temporary egg taking station for steelhead trout on the Salmon River, a tributary of the Sandy River. The following year, eggs were taken at Willamette Falls and again at the Sandy River station. The State also did some experimental steelhead trout research work on the upper Columbia River and its tributaries.

In 1909, the State constructed Bonneville Hatchery on Tanner Creek near the present site of Bonneville Dam. It was designed as a central hatching station, receiving all of its eggs from other facilities on the river. With a capacity of approximately 60 million eggs, it was one of the largest on the coast. Prior to Bonneville's construction there were no significant runs of salmon into Tanner Creek. After a number of years of rearing the transferred eggs and releasing fry into Tanner Creek, adult fish began to return to Bonneville at maturity. These developed stocks of fish became the hatchery's main egg source and the transfer programs were scaled down. In the past several years Bonneville has been able to rely on its egg source and actually supply surplus for other stations.

In 1920, the Legislature split the Oregon Fish and Game Commission's responsibility for anadromous fish between two new agencies: the Fish Commission of Oregon (FCO) took over salmon production and the Oregon Game Commission (OGC) concentrated on steelhead and sea-run cutthroat trout. The existing hatcheries were realigned under these two agencies, those raising primarily steelhead trout were placed under the OGC and those raising primarily salmon under the FCO.

In 1976, there were 15 hatcheries and 4 ponds operated in this region by the USFWS and Oregon Department of Fish and Wildlife (ODFW) (Table 19). As noted in the tables, the FCO and OGC were recombined into the ODFW in 1975. Most of the current facilities are concentrated near the mouth of the Columbia River, on the Willamette and Deschutes River systems, or near Bonneville Dam (Fig. 8). Wallowa Hatchery, located in ex-

Table 12.—Migrant releases of chinook and coho salmon and steelhead trout—Pacific coast by Columbia River Development Program hatcheries[1] (in thousands).

Release year	Fall chinook		Spring chinook		Summer chinook		Coho		Winter steelhead		Summer steelhead	
	Number	Pounds[2]	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
1960	89,105.2	329.7	1,836.1	60.2	0.0	0.0	6,359.8	217.6	916.9	124.7	67.5	11.3
1961	46,640.1	305.5	827.3	30.0	0.0	0.0	14,182.8	507.4	605.1	65.2	303.1	43.2
1962	55,783.6	283.3	1,666.8	57.7	0.0	0.0	12,863.8	571.4	1,408.9	110.4	227.2	28.6
1963	58,845.0	325.8	2,391.4	85.0	0.0	0.0	19,589.1	756.8	1,027.7	83.9	366.7	53.6
1964	65,501.5	407.5	7,643.3	220.8	0.0	0.0	16,529.8	775.3	1,106.7	145.6	562.3	87.1
1965	56,191.0	370.5	3,042.4	102.0	0.0	0.0	17,919.4	853.9	1,352.9	174.8	595.3	73.5
1966	54,944.7	488.9	3,812.4	111.5	0.0	0.0	21,170.4	1,074.7	1,733.1	206.5	745.7	101.8
1967	55,118.5	497.8	5,484.8	177.5	0.0	0.0	20,208.9	1,000.3	1,411.1	161.4	855.7	126.3
1968	55,514.9	595.5	3,788.8	166.8	0.0	0.0	15,715.2	866.9	1,425.9	149.3	1,527.7	175.7
1969	57,927.3	574.1	3,496.8	164.4	0.0	0.0	18,620.3	1,103.7	1,494.9	171.6	822.7	96.6
1970	62,175.2	689.6	2,578.7	148.3	393.8	9.8	17,450.8	1,002.7	1,363.6	196.9	1,525.6	258.1
1971	63,277.3	483.3	3,784.3	238.9	400.3	13.9	21,281.2	1,207.2	1,287.4	151.7	1,130.3	156.1
1972	67,053.7	721.8	3,619.8	253.1	231.7	13.3	23,887.6	1,520.5	1,315.3	172.8	1,233.0	198.7
1973	70,384.2	831.4	4,822.9	401.3	217.1	4.3	20,879.2	1,196.4	1,385.9	223.5	1,151.4	189.4
1974	65,476.3	887.5	4,423.5	269.2	330.0	8.1	20,163.6	1,177.4	1,137.9	162.7	1,168.5	176.7
1975	70,455.2	918.9	5,229.8	326.7	114.6	2.9	21,104.2	1,382.9	937.3	144.7	1,025.3	153.9
1976	80,866.8	1,108.1	5,933.6	479.8	406.6	15.8	22,217.8	1,325.9	1,216.7	184.9	950.4	150.5
Total	1,075,260.5	9,819.2	64,382.7	3,293.2	2,094.1	68.1	310,143.9	16,541.0	21,127.3	2,630.6	14,258.4	2,081.1

[1] Derived from Wahle et al. (1975) prior to 1974, Foster et al. (see footnote 1, Table 8) for WDF 1974, Fletcher et al. (see footnote 1, Table 8) for WDF 1975, Foster et al. (1977) for WDF 1976, and from WDG release records and USFWS hatchery annual reports.

[2] 1 lb = 0.454 kg.

Table 13.—Migrant releases of chum and cherry salmon and sea-run cutthroat trout—Pacific coast-Columbia River Development Program hatcheries[1] (in thousands).

Release year	Chum		Cherry		Sea-run cutthroat	
	Number	Pounds[2]	Number	Pounds	Number	Pounds
1960	0.0	0.0	0.0	0.0	0.0	0.0
1961	63.6	0.4	0.0	0.0	6.9	0.8
1962	717.5	1.8	0.0	0.0	0.0	0.0
1963	1,770.8	2.5	0.0	0.0	6.4	0.8
1964	150.8	0.2	0.0	0.0	82.5	10.0
1965	205.3	0.3	0.0	0.0	85.9	13.6
1966	738.1	2.4	0.0	0.0	41.5	6.7
1967	524.1	3.0	0.0	0.0	119.4	23.9
1968	173.6	0.6	0.0	0.0	121.2	25.8
1969	129.9	0.3	0.0	0.0	35.3	7.5
1970	62.5	0.1	0.0	0.0	50.0	10.6
1971	0.0	0.0	0.0	0.0	40.1	8.0
1972	638.5	1.2	0.0	0.0	22.8	5.7
1973	563.6	1.4	1.8	0.1	27.0	9.0
1974	627.3	3.4	0.0	0.0	4.3	1.1
1975	0.0	0.0	0.0	0.0	0.0	0.0
1976	1,126.8	4.7	0.0	0.0	0.0	0.0
Total	7,492.4	22.3	1.8	0.1	643.3	123.5

[1] Derived from Wahle et al. (1975) prior to 1974, Foster et al. (see footnote 1, Table 8) for WDF 1974, Fletcher et al. (see footnote 1, Table 8) for WDF 1975, Foster et al. (1977) for WDF 1976, and from WDG release records and USFWS hatchery annual reports.

[2] 1 lb = 0.454 kg.

treme eastern Oregon near Enterprise, is the only exception.

Migrant releases from Oregon Columbia Basin hatcheries represent 20% (698 million migrants) of the 1960-76 Pacific coast total by number and 19% [20.3 million pounds (9.2 million kg)], by weight (Tables 20, 21). Fall chinook salmon, with 44 million migrants released, was the main species by number reared in 1976 followed by coho salmon, spring chinook salmon, and steelhead trout. The same year, the largest release by weight was of coho salmon, 600,000 lb (272,200 kg) followed by fall chinook salmon, spring chinook salmon, and steelhea trout.

The Columbia River Development Progr ("Program") had an important impact on anadromou fish in Oregon's portion of the Columbia Basin. F were provided for stream clearance and improveme well as for fishway and hatchery construction or recon struction. Fishways were built on the Clatskanie River Eagle Creek, and Scappoose Creek, among others, the existing fishway at Willamette Falls was rebuilt streams such as the Calpooia and Clatskanie Rivers a well as Big, Tide, Goble, Eagle, Deep, Clear, Abernathy and Delph Creeks, where needed, accumulated de log jams, and splash dams were removed. The State eries agencies screened problem irrigation diversio ditches and canals to prevent loss of trout and salmo fingerlings. Sandy, Cascade, Eagle Creek, and Creek hatcheries were constructed under the Progr Bonneville, Oxbow, Klaskanine, and Big Creek hatcher ies were either renovated or completely reconstruct

One of the major accomplishments of the Progra Oregon was the development or improvement of runs several salmonid species in the area above Willamett Falls. A three-part project, the initial phase was a operative study of passage problems over Willam Falls. Monies were then provided to stock the uppe Willamette River and its tributaries as well as for strear clearance and improvement. In the final phase, Program provided the major portion of funding the million fishway. As a result of these efforts, runs of fa chinook salmon and summer steelhead trout have bee developed and spring chinook and coho salmon hav creased.

Oregon Coastal

The first anadromous fish facility on the Oregon coas

Table 14.—Anadromous fish rearing facilities—Columbia basin-Washington, 1960-76.

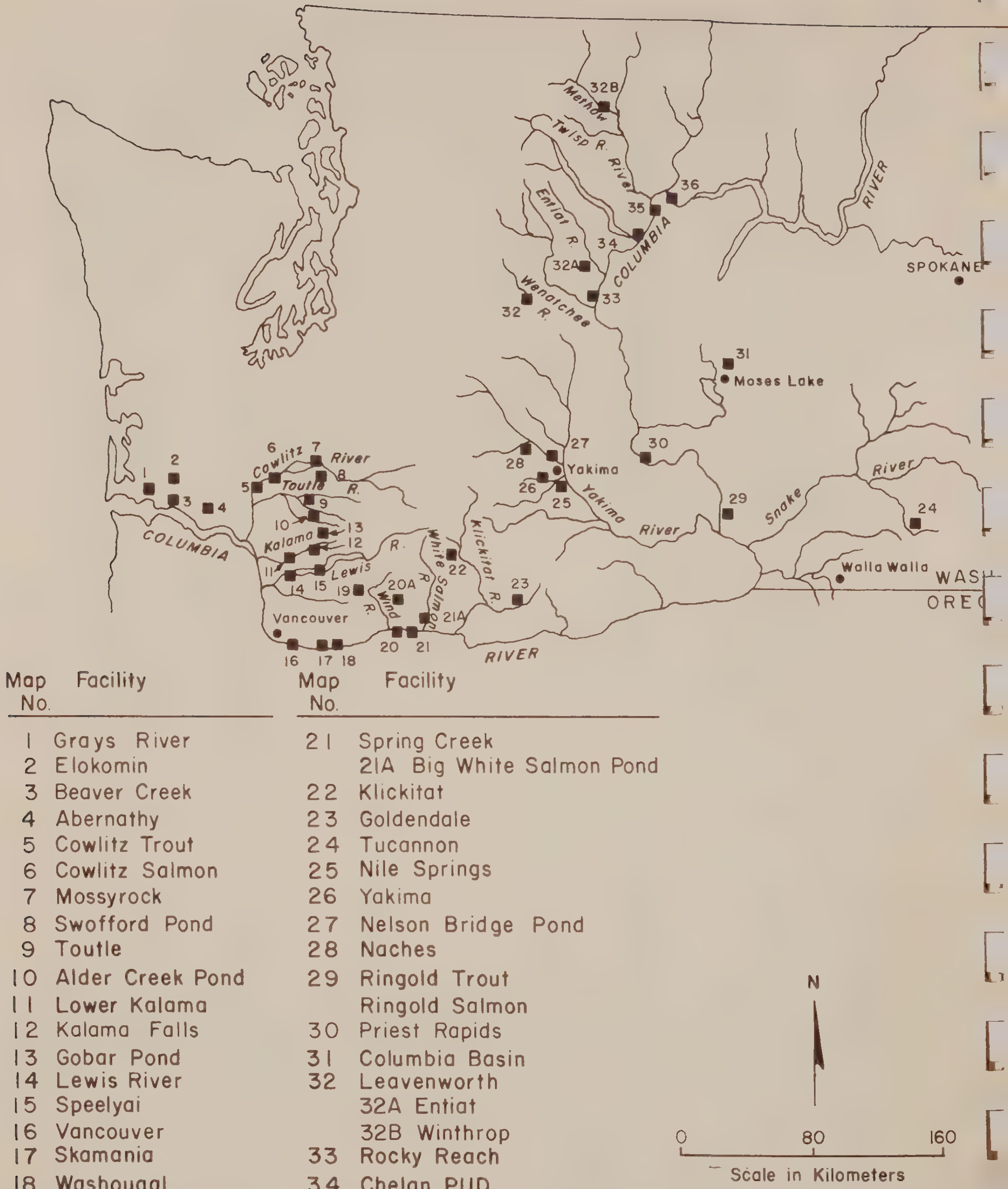
Facility	General location	Operating agency[1]	Species reared during year span[2]	Anadromous releases in 1976	Year anadromous operation began	Funding agency[1]
tcheries						
thy	Longview	USFWS	fc (sc, co, sh)	Yes	1959	USFWS, NMFS
Creek	Cathlamet	WDG	sh, src	Yes	1958	NMFS
Carson	Carson	USFWS	sc (fc, co, sh)	Yes	1937	USFWS, NMFS
Chelan PUD	Chelan	WDG	sh	Yes	1964	Chelan PUD
bia Basin	Moses Lake	WDG	sh	Yes	1961	Chelan PUD
z Salmon	Salkum	WDF	fc, sc, co	Yes	1967	Tacoma P&L
Cowlitz Trout	Ethel	WDG	sh, src	Yes	1967	Tacoma P&L
Elokomin	Cathlamet	WDF	fc, co (ch)	Yes	1954	NMFS
Goldendale	Goldendale	WDG	sh	No	1943	WDG
River	Grays River	WDF	fc, co, ch	Yes	1961	NMFS
a Falls	Kalama	WDF	fc, sc, co	Yes	1959	NMFS
Klickitat	Glenwood	WDF	fc, sc, co	Yes	1950	NMFS
Leavenworth complex	Leavenworth	USFWS	sc, co, sk (fc)	Yes	1938	USFWS
Entiat	Entiat	USFWS	smc (sc, co)	Yes	1942	USFWS
throp	Winthrop	USFWS	sms (fc, sc, co, sh)	Yes	1967	USFWS
River	Woodland	WDF	co (fc, sc)	Yes	1909	WSF, Pacific P&L
Little White Salmon complex	Cook	USFWS	fc, sc, co (ch)	Yes	1898	USFWS, NMFS
Willard	Cook	USFWS	co (sc)	Yes	1951	NMFS, USFWS
Kalama	Kalama	WDF	fc, co	Yes	1895	WDF
rock	Mossyrock	WDG	sh, src	Yes	1972	Tacoma P&L
Naches	Yakima	WDG	sh	Yes	1933	WDG
Skamania	Washougal	WDG	sh (fc)	Yes	1956	NMFS, WDG
Speelyai	Yale	WDF	sc, co (fc)	Yes	1958	Pacific P&L
Creek	Underwood	USFWS	fc (co)	Yes	1901	USFWS, NMFS, Corps
White Salmon pond	Underwood	USFWS	fc, co	Yes	1901	USFWS, NMFS, Corps
Toutle	Toutle	WDF	fc, sc, co	Yes	1952	NMFS
Tucannon	Pomeroy	WDG	sh	Yes	1971	WDG
uver	Vancouver	WDG	sh, src	Yes	1936	WDG
ugal	Washougal	WDF	fc, co (ce)	Yes	1958	NMFS
Wells Trout	Azwell	WDG	sh	Yes	1968	Douglas Co. PUD
Yakima	Yakima	WDG	sh	Yes	1937	WDG
aring Ponds						
Creek	Toutle	WDG	sh	Yes	1973	NMFS, WDG
	Toutle	WDG	sh	Yes	1975	NMFS, WDG
Nelson Bridge	Yakima	WDG	sh	No	1964	WDG
Nile Springs	Yakima	WDF, Sportsmen Group	sc	Yes	1976	Sportsmens Group
Rapids	Priest Rapids Dam	WDF	fc	Yes	1972	Grant PUD
d Salmon	Ringold	WDF	fc, sc, co	Yes	1962	NMFS
Ringold Trout	Ringold	WDG	sh	Yes	1962	NMFS
Rocky Reach	Wenatchee	WDF	fc, co	Yes	1970	Chelan PUD
rd Island	Mossyrock	WDG	sh	Yes	1968	WDG
burn Island	Brewster	WDG	sh	No	1966	Douglas PUD
Wells Salmon	Azwell	WDF	fc, sc, smc, co	Yes	1968	Douglas PUD

[1] USFWS = U.S. Fish and Wildlife Service, NMFS = National Marine Fisheries Service, WDG = Washington Department of Game, WDF = Wash- Department of Fisheries, Chelan PUD = Chelan County Public Utility Division, Tacoma P & L = Tacoma Power and Light, Pacific P&L = Pacific nd Light, Corps = U.S. Army Corps of Engineers, Douglas PUD = Douglas County Public Utility Division, Grant PUD = Grant County Public ility Division.

[2] fc = fall chinook salmon, sc = spring chinook salmon, smc = summer chinook salmon, co = coho salmon, sh = steelhead trout, ch = chum salmon, c = sea-run cutthroat trout, sk = sockeye salmon, ce = cherry salmon.

as a private hatchery constructed by R. D. Hume. The ry was completed in 1877 on a site near Ellens- n the lower Rogue River. Hume, a local salmon cker, operated the hatchery without assistance for 11 . In 1889, the Oregon Legislature supported his efforts onies appropriated for enlargement as well as for on and maintenance of the hatchery. Hume con- nued to operate the facility until his death in 1908 at time it was turned over to the State. He built r hatchery in 1897 on the Rogue River at the outh of Oak Creek. The U.S. Fish Commission, as agreed prior to construction, assumed responsibility for operating this hatchery after its completion.

Hume was an early developer of hatchery techniques. He is credited with the concept of adult holding ponds. The adult chinook salmon needed for the hatchery egg supply were trapped in tidewater on their way to the upper Rogue River. At trapping, these fish had not yet reached sexual maturity. Hume constructed a large, concrete-lined, covered holding pond to retain the fish until spawning time. Most present day hatcheries are built with a similar type adult holding facility.


328
Methow
Twisp R.
River
36
35
RIVER
Entiat R.
34
COLUMBIA
32A
SPOKANE
Wenatchee R.
33
32
31
Moses Lake
6
Cowlitz
7
River
2
1
8
5
Toutle R.
3
4
9
27
30
28
Yakima
26
25
Yakima
River
29
Snake
River
24
10
13
12
Kalama
COLUMBIA
R.
White Salmon R.
Klickitat R.
22
11
Lewis
14
15
19
20A
Wind R.
23
Walla Walla
WAS
ORE
Vancouver
21A
16
17
18
20
21
RIVER
N
0
80
160
Scale in Kilometers

Map No.	Facility
1	Grays River
2	Elokomin
3	Beaver Creek
4	Abernathy
5	Cowlitz Trout
6	Cowlitz Salmon
7	Mossyrock
8	Swofford Pond
9	Toutle
10	Alder Creek Pond
11	Lower Kalama
12	Kalama Falls
13	Gobar Pond
14	Lewis River
15	Speelyai
16	Vancouver
17	Skamania
18	Washougal
19	Carson
20	Little White Salmon
	20A Willard
21	Spring Creek
	21A Big White Salmon Pond
22	Klickitat
23	Goldendale
24	Tucannon
25	Nile Springs
26	Yakima
27	Nelson Bridge Pond
28	Naches
29	Ringold Trout
	Ringold Salmon
30	Priest Rapids
31	Columbia Basin
32	Leavenworth
	32A Entiat
	32B Winthrop
33	Rocky Reach
34	Chelan PUD
35	Wells Trout Hatchery
	Wells Salmon Pond
36	Washburn Island

Figure 6.—Map of locations of Columbia Basin-Washington salmonid rearing facilities, 1960-76.

Table 15.—Migrant releases of chinook and coho salmon and steelhead trout—Columbia Basin-Washington[1] (in thousands).

Release year	Fall chinook		Spring chinook		Summer chinook		Coho		Winter steelhead		Summer steelhead	
	Number	Pounds[2]	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
1960	57,338.0	242.0	1,218.1	39.1	0.0	0.0	3,849.0	93.2	545.1	64.8	136.4	20.9
1961	33,531.9	241.5	667.7	27.1	0.0	0.0	9,161.6	259.3	586.5	73.1	417.6	57.2
1962	42,537.5	233.2	1,822.5	61.2	0.0	0.0	6,802.2	197.0	715.5	97.0	355.5	41.1
1963	42,646.2	238.7	1,680.9	55.3	0.0	0.0	15,096.9	428.9	568.7	74.4	767.2	95.0
1964	40,611.0	240.8	3,607.1	120.3	0.0	0.0	9,833.6	401.5	647.6	111.3	1,192.0	166.8
1965	37,073.6	234.4	2,072.4	77.7	0.0	0.0	13,950.5	557.5	943.7	151.8	1,176.7	135.4
1966	38,121.2	322.5	2,425.4	67.1	0.0	0.0	17,932.4	811.1	879.1	117.1	1,175.5	150.0
1967	34,969.8	313.1	3,269.7	122.0	0.0	0.0	15,092.7	709.6	992.8	138.1	1,460.3	214.0
1968	42,448.4	405.5	2,399.9	121.0	2,138.3	13.6	12,256.9	653.3	792.2	114.4	1,904.9	237.2
1969	45,846.5	459.1	3,876.2	317.4	2,121.3	20.2	20,808.5	1,181.1	782.6	110.0	1,948.9	257.8
1970	52,857.2	541.4	5,633.1	527.5	3,834.4	25.6	18,441.7	1,054.7	1,399.9	209.7	2,292.3	355.9
1971	50,830.3	421.3	6,706.0	530.3	1,784.2	23.1	23,336.8	1,330.6	1,493.0	184.6	1,813.8	236.5
1972	58,504.5	651.5	7,063.5	712.8	2,373.2	29.3	22,445.3	1,450.0	1,185.7	154.2	1,990.4	298.9
1973	61,036.0	751.1	5,899.1	635.5	2,095.5	30.0	21,317.9	1,266.1	1,815.9	269.0	1,578.6	249.4
1974	57,986.7	844.0	6,826.0	584.4	872.8	34.9	20,616.4	1,257.8	1,187.2	157.0	1,618.0	231.9
1975	60,938.2	867.0	7,863.2	729.7	0.0	0.0	21,785.9	1,440.6	1,099.5	153.9	1,789.0	259.3
1976	58,174.1	816.8	9,431.8	877.9	294.0	18.2	20,573.6	1,223.8	1,325.3	212.9	1,461.4	231.9
Total	815,451.1	7,823.9	72,462.6	5,606.3	15,513.7	194.9	273,301.9	14,316.1	16,960.3	2,393.3	23,078.5	3,239.2

[1] Derived from Wahle et al. (1975) prior to 1974, Foster et al. (see footnote 1, Table 8) for WDF 1974, Fletcher et al. (see footnote 1, Table 8) for WDF 1975, Foster et al. (1977) for WDF 1976, and from WDG release records and USFWS hatchery annual.

[2] 1 lb = 0.454 kg.

6.—Migrant releases of chum, sockeye, and cherry salmon a-run cutthroat trout—Columbia Basin-Washington[1] (in ousands).

year	Chum		Sockeye		Cherry		Sea-run cutthroat	
	No.	Lb.[2]	No.	Lb.	No.	Lb.	No.	Lb.
1960	0.0	0.0	3,177.0	69.2	0.0	0.0	0.0	0.0
	50.8	0.3	2,788.0	72.5	0.0	0.0	6.9	0.8
	402.9	1.2	2,224.0	43.8	0.0	0.0	0.0	0.0
196	1,489.9	2.1	3,121.0	67.8	0.0	0.0	6.4	0.8
1964	150.8	0.2	3,364.0	58.8	0.0	0.0	82.5	10.0
1965	205.3	0.3	3,301.0	73.6	0.0	0.0	85.9	13.6
	422.7	0.4	73.0	1.6	0.0	0.0	87.0	17.5
	152.1	0.2	0.0	0.0	0.0	0.0	182.5	38.5
1968	38.6	0.1	0.0	0.0	0.0	0.0	248.2	52.5
1969	47.3	0.1	23.4	0.7	0.0	0.0	261.3	50.3
	62.5	0.1	0.0	0.0	0.0	0.0	302.3	55.2
	0.0	0.0	0.0	0.0	0.0	0.0	364.3	65.1
	638.5	1.2	0.0	0.0	0.0	0.0	159.2	37.2
1973	563.6	1.4	0.0	0.0	1.8	0.1	202.4	46.3
1974	627.3	3.4	0.0	0.0	0.0	0.0	150.3	31.9
	0.0	0.0	0.0	0.0	0.0	0.0	139.6	32.8
	1,126.8	4.7	0.0	0.0	0.0	0.0	151.8	34.6
Total	5,979.1	15.7	18,071.4	388.0	1.8	0.1	2,430.6	487.1

[1] Derived from Wahle et al. (1975) prior to 1974, Foster et al. (see foot- Table 8) for WDF 1974, Fletcher et al. (see footnote 1, Table 8) 1975, Foster et al. (1977) for WDF 1976, and from WDG release cords and USFWS hatchery annual reports.

[2] 1 lb = 0.454 kg.

he was also one of the first to raise anadromous fish r than fry size on a production basis. Prior to his ork, and in many cases afterwards, fish were released ter absorption of the yolk sac. A few fish were to fingerling and yearling size as a curiosity. While ising fish to larger sizes was not physically difficult, in- reased cost and need for larger facilities prevented the adoption of the rearing procedure. Hume, among correctly predicted higher survival of larger fish ith little increased costs of rearing. Presently, all anadromous facilities, with the exception of several chum and pink salmon hatcheries, rear their production fish for at least 30 days.

In the 1890's and early 1900's, there were hatcheries or egg taking stations built on most of Oregon's coastal streams. In 1902 alone, hatcheries were built on the Coquille, Siuslaw, Alsea, Yaquina, and Tillamook Rivers. One of these, built by the State on the Siuslaw River and then turned over to the U.S. Fish Commission, is interesting because of the reason for its failure. Adult fish were unable to reach the hatchery because fishermen working downstream blocked fish passage with nets stretched completely across the river. This is an extreme example of the intensive coast-wide pressure placed on the resource.

In 1920, the responsibility for rearing anadromous salmonids was split between the newly formed FCO and the OGC. By 1929, there were 10 State hatcheries and 1 Federal hatchery in operation. The total accumulated production through 1929 was almost 650 million fish with most coming from State facilities. Emphasis was placed on fall chinook and coho salmon which accounted for 56% and 31% of these releases, respectively.

There are presently 12 hatcheries in operation on the major coastal tributaries (Figs. 9, 10). Up until 1975 when the two State fisheries agencies were recombined to form the Oregon Department of Fish and Wildlife, five of these were operated by FCO and another five by OGC (Table 22). Nine of the 10 State hatcheries were built to enhance existing or depleted runs. The tenth, Cole Rivers Hatchery, is similar to many of the Columbia Basin facilities in that it was built on the Rogue River to compensate for the loss of spawning grounds and resultant fish from Lost Creek Dam.

In 1976, species reared in the greatest numbers at Oregon coastal hatcheries were coho salmon, fall chinook

Table 17.—Anadromous fish rearing facilities—Columbia Basin-Idaho, 1960-76.

Facility	General location	Operating agency[1]	Species reared during year span[2]	Anadromous releases in 1976	Year anadromous operation began	Funding agency[1]
Hatcheries						
Dworshak	Orofino	USFWS	sh	Yes	1969	USFWS, Corps
Eagle	Boise	IDFG	smc	Yes	1976	IDFG
Hagerman	Hagerman	IDFG	smc, sh (sc)	Yes	1969	IDFG
Hayden Creek	Salmon	IDFG	sc, sh	Yes	1973	NMFS, IDFG, USFWS
Kooskia	Kooskia	USFWS	sc	Yes	1966	USFWS
MacKay	MacKay	IDFG	smc	Yes	1976	NMFS
McCall	McCall	IDFG	smc	Yes	1976	IDFG, PNRC
Mullen	Mullen	IDFG	sc	Yes	1976	IDFG
Niagara Springs	Buhl	IDFG	sh	Yes	1966	Idaho Power Co.
Oxbow	Oxbow Dam	IDFG	fc	No	1964	Idaho Power Co.
Pahsimeroi	Challis	IDFG	smc, sh	Yes	1970	IDFG, NMFS
Rapid River	Riggins	IDFG	sc	Yes	1964	Idaho Power Co.
Sandpoint	Sandpoint	IDFG	sc	Yes	1972	IDFG, NMFS
Ponds						
Decker Flats	Stanley	IDFG	sc	No	1968	USFWS, NMFS, IDFG

[1] USFWS = U.S. Fish and Wildlife Service, Corps = U.S. Army Corps of Engineers, IDFG = Idaho Department of Fish and Game, NMFS = National Marine Fisheries Service, PNRC = Pacific Northwest Regional Commission.

[2] fc = fall chinook salmon, sc = spring chinook salmon, smc = summer chinook salmon, sh = steelhead trout (minor species in parentheses).

salmon, and winter steelhead trout, respectively. Summer steelhead trout and spring chinook salmon also accounted for a substantial number of releases. The first three represented 52%, 19%, and 13% of the migrant numbers released (Table 23).

There are also two private fish cultural operations active on the coast. They are a part of a new concept in commercial rearing of salmon by private companies termed "ocean ranching." Ocean ranching consists of raising fish to migrant size, releasing them into the ocean, and recovering returning adults. In Oregon, these returnees can then be sold commercially, hopefully at a profit, by the company. The enterprises are licensed by ODFW and must receive their initial egg supply from hatchery excesses at the State hatcheries. After their returns reach a sufficient number, the private hatcheries will be able to secure their own eggs without having to depend on the State. The primary species to be raised at these private facilities will be chinook, coho, and chum salmon.

California

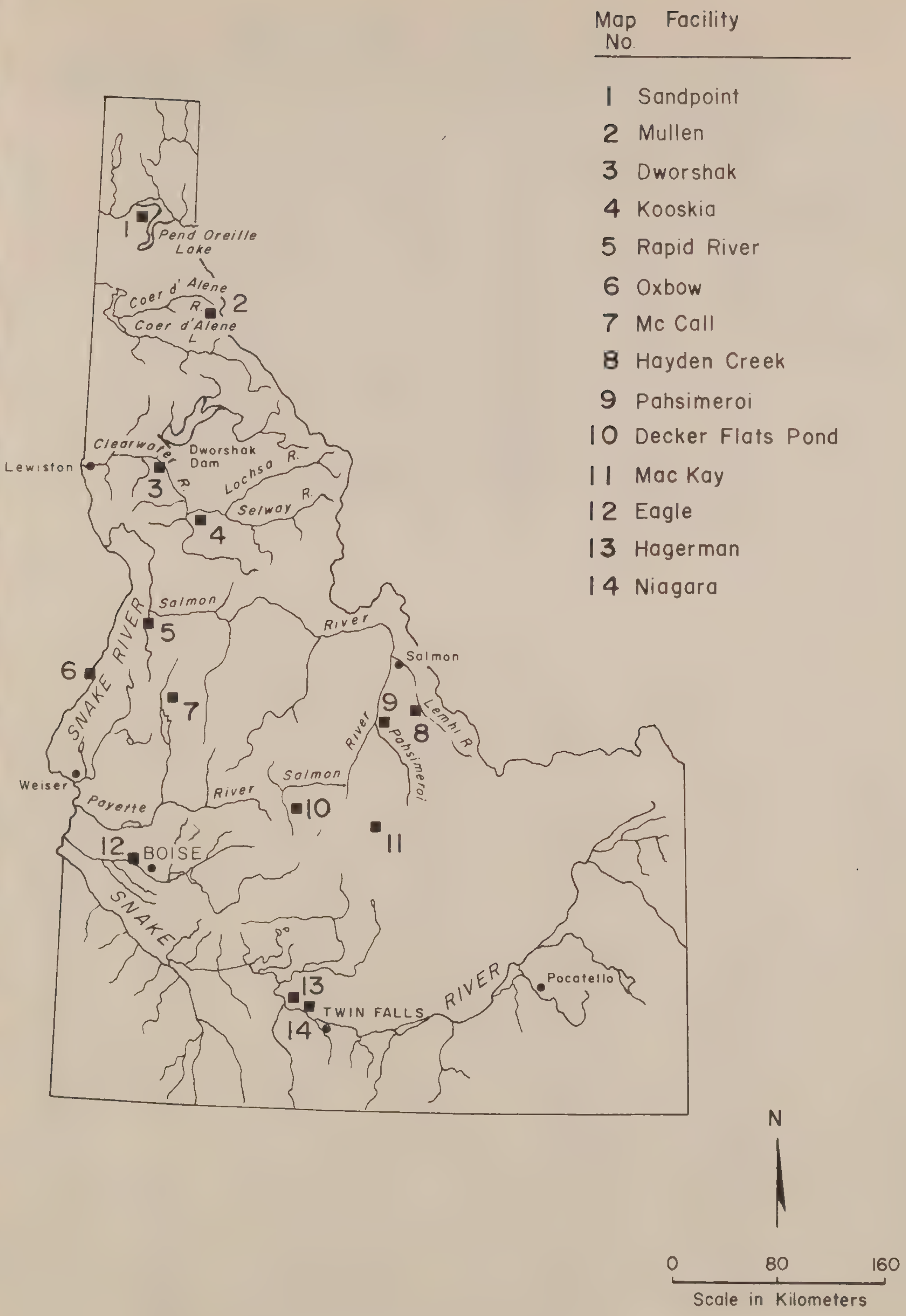
Anadromous salmonid production on the Pacific coast began in California in 1872 with the activities of Livingston Stone. The Federally operated fish hatchery he built on the McCloud River was first used solely as a collection site for eggs to be shipped to the east coast. After several years, the U.S. Bureau of Fisheries cooperated with the State in egg shipments and fry releases in local streams to augment natural spawning. The first State operated salmon hatchery was authorized and constructed in 1885 on Hat Creek, a tributary of the Pit River. The local source of chinook salmon eggs proved inadequate so operations were transferred in 1888 to the newly constructed Mt. Shasta Hatchery on a site near Sisson in Siskiyou County. This station is still in full-scale operation producing rainbow trout, making it the oldest functi
hatchery on the west coast (Leitritz 1970).

Up to the 1920's, many State and Federal hat
were built in northern California on the Klamath
Sacramento Rivers and their tributaries. There we
hatcheries on coastal tributaries such as the Ee
sian, and Mad Rivers. A hatchery operated by the
of Santa Cruz at Brookdale was the most southerly l
tion of early fish cultural operations.

Plants from these early hatcheries were made th
out the Sacramento and Klamath River drainag
most northern coastal streams. Some releases were m
as far south as the Ventura River, south of Sant
bara. While the majority of these fish were fall c
salmon, the State hatcheries also liberated a few c
salmon fry. In 1902, the State hatcheries began a s
stantial steelhead trout program. As fish propa
was a cóoperative effort between the Federal and
governments, the Federal hatcheries supplied a l
portion of the eggs that State hatcheries reared
release. In 1914, the Federal installations began to
cially feed the small fall chinook salmon and
them as fingerlings or yearlings rather than plan
them as unfed fry. This followed the example set by
Hume in Oregon.

In 1976, 1 Federal, 10 State, and 2 private hatc
and ponds were operated in California (Table 24). Of
13, 6 are on tributaries of the Sacramento River (F
Fall chinook salmon, coho salmon, and winter ste
trout are the three primary species reared in Califor
but the hatcheries are also undertaking spring chi
salmon and summer steelhead trout programs
25).

As shown in the "Funding Agency" column of T
22, over one-half of the hatcheries and ponds are ei
partially or wholly supported by organizations oth
the California Department of Fish and Game.


Pend Oreille Lake
Coer d' Alene R.
Coer d'Alene L
Clearwater R.
Dworshak Dam
Lewiston
Lochsa R.
Selway R.
Salmon River
Snake River
Salmon
Lemhi R.
River Pahsimeroi
Salmon River
Weiser
Payette River
BOISE
SNAKE RIVER
TWIN FALLS
Pocatello
1
2
3
4
5
6
7
8
9
10
11
12
13
14
N
0
80
160
Scale in Kilometers

Map No.	Facility
1	Sandpoint
2	Mullen
3	Dworshak
4	Kooskia
5	Rapid River
6	Oxbow
7	Mc Call
8	Hayden Creek
9	Pahsimeroi
10	Decker Flats Pond
11	Mac Kay
12	Eagle
13	Hagerman
14	Niagara

Figure 7.—Map of locations of Columbia Basin-Idaho salmonid rearing facilities, 1960-76.

Table 18.—Migrant releases of chinook salmon and steelhead trout—Columbia Basin-Idaho[1] (in thousands).

Release year	Fall chinook		Spring chinook		Summer chinook		Summer steelhead	
	Number	Pounds[2]	Number	Pounds	Number	Pounds	Number	Pounds
1960	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1961	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1962	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1963	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1964	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1965	1,282.3	5.7	0.0	0.0	0.0	0.0	24.1	2.6
1966	214.7	1.3	580.0	25.7	0.0	0.0	138.8	15.5
1967	1,473.5	5.9	449.3	19.4	0.0	0.0	1,364.8	121.9
1968	202.3	1.1	1,471.5	58.5	0.0	0.0	2,034.2	228.1
1969	255.5	1.9	1,057.6	40.9	0.0	0.0	1,732.5	185.3
1970	497.3	2.3	3,377.0	177.2	393.8	9.8	3,173.3	491.7
1971	0.0	0.0	3,489.3	172.5	400.3	13.9	4,932.0	634.8
1972	0.0	0.0	3,954.6	198.2	231.7	13.3	2,585.1	411.2
1973	0.0	0.0	3,830.5	206.3	217.1	4.3	4,619.6	400.0
1974	0.0	0.0	3,511.8	187.9	330.0	8.1	6,340.0	752.6
1975	0.0	0.0	5,134.1	309.9	114.6	2.9	3,511.6	520.4
1976	0.0	0.0	5,994.6	354.8	523.7	22.3	3,774.4	487.4
Total	3,925.6	18.2	32,850.3	1,751.3	2,211.2	74.6	34,230.4	4,251.5

[1] Derived from Wahle et al. (1975) prior to 1974, Idaho Department of Fish and Game release records, and U.S. Fish and Wildlife Service hatchery annual reports.

[2] 1 lb = 0.454 kg.

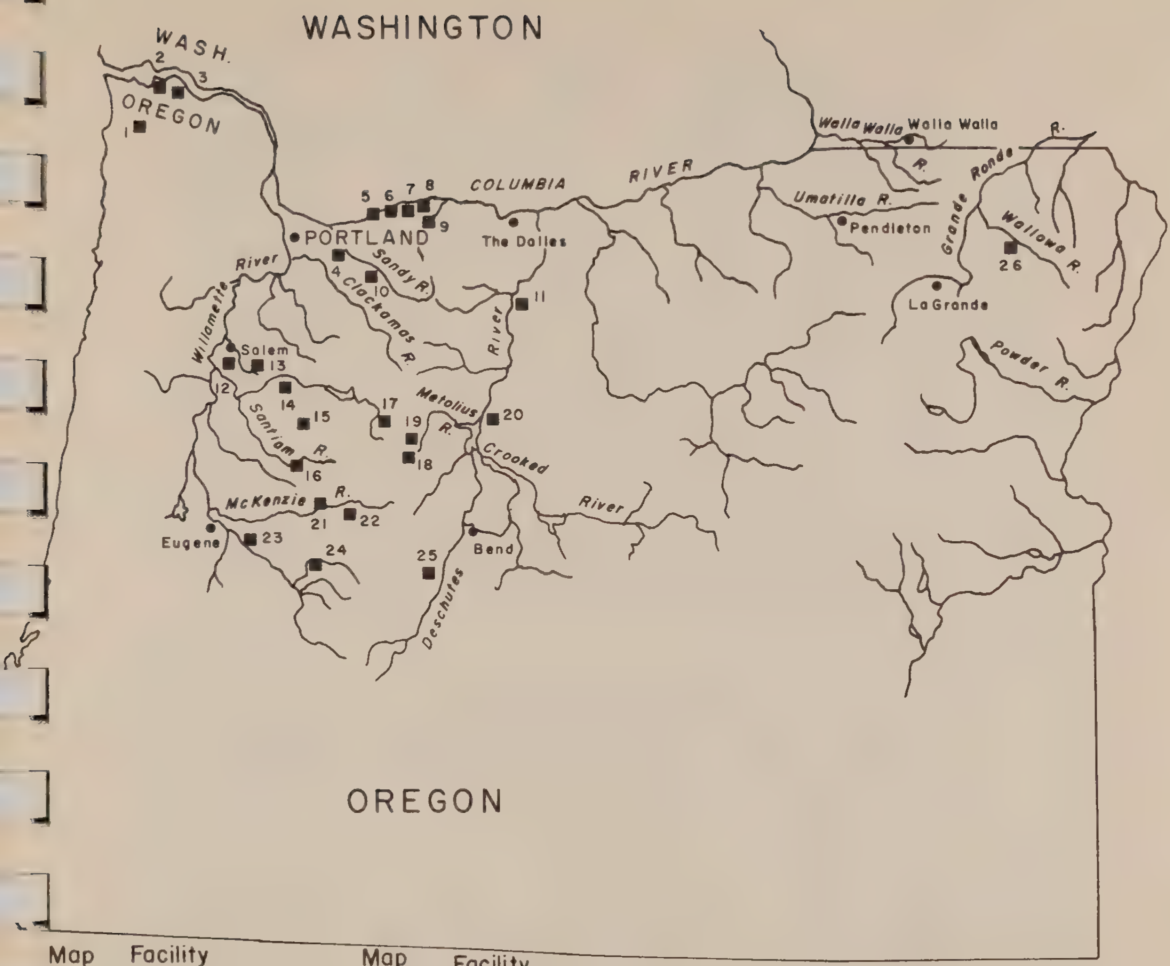
Table 19.—Anadromous fish rearing facilities—Columbia Basin-Oregon, 1960-76.

Facility	General location	Operating agency[1,3]	Species reared during year span[2]	Anadromous releases in 1976	Year anadromous operation began	Funding Agency
Hatcheries						
Big Creek	Knappa	ODFW (FCO)	fc, co, sh (ch)	Yes	1938	NMFS, Orego
Bonneville	Bonneville	ODFW (FCO)	fc, co (sh)	Yes	1909	NMFS, Oregon, C
Cascade	Cascade Locks	ODFW (FCO)	fc, co (sc, ch)	Yes	1958	NMFS
Eagle Creek	Estacada	USFWS	sc, co, sh (fc)	Yes	1957	NMFS
Fall River	LaPine	ODFW (OGC)	sc	No	1929	Oregon
Gnat Creek	Westport	ODFW (OGC)	sh (fc, sc, ch)	Yes	1960	NMFS
Hood River	Dee	ODFW (OGC)	co, sh	No	1958	Oregon
Klaskanine	Astoria	ODFW (FCO)	fc, co, sh	Yes	1911	NMFS, Orego
Leaburg	Leaburg	ODFW (OGC)	sc (co, sh)	Yes	1954	Corps
Marion Forks	Idanha	ODFW (FCO)	sc, sh	Yes	1950	Corps, Oregon
McKenzie	Leaburg	ODFW (FCO)	sc (co)	Yes	1930	Corps, Oregon
Metolius	Camp Sherman	ODFW (FCO)	sc, sh	No	1947	Oregon
Oakridge (Willamette)	Oakridge	ODFW (FCO)	sc (co)	Yes	1911	Oregon, Corps
Oak Springs	Maupin	ODFW (OGC)	sh (sc)	Yes	1920	Oregon
Oxbow	Cascade Locks	ODFW (FCO)	fc, sc (co)	Yes	1938	NMFS, Orego
Roaring River	Scio	ODFW (OGC)	sh	Yes	1925	Oregon
Round Butte	Madras	ODFW (OGC)	sc, smc, sh	Yes	1972	PGE
Sandy	Sandy	ODFW (FCO)	fc, co (sc, sh)	Yes	1950	NMFS
South Santiam	Foster	ODFW (FCO)	sc, sh (fc)	Yes	1923	Corps, Oregon
Wallowa	Enterprise	ODFW (OGC)	sh	No	1924	Oregon
Wizard Falls	Camp Sherman	ODFW (OGC)	sc, sh	No	1949	Oregon
Ponds						
Aumsville	Aumsville	ODFW (FCO)	fc	Yes	1970	Oregon, NMF
Dexter	Dexter	ODFW (FCO)	sc	Yes	1955	Corps, Oregon
Salem	Salem	ODFW (FCO)	fc	No	1968	Oregon, NMFS
Stayton	Stayton	ODFW (FCO)	fc	Yes	1969	Oregon, NMFS
Wahkenn	Bonneville	ODFW (FCO)	fc, co	Yes	1961	NMFS

[1] Present agency with premerger agency in parentheses.

[2] fc = fall chinook salmon, sc = spring chinook salmon, co = coho salmon, sh = steelhead trout, ch = chum salmon (minor species in parentheses)

[3] ODFW = Oregon Department of Fish and Wildlife, OGC = Oregon Game Commission, FCO = Fish Commission of Oregon, NMFS =National rine Fisheries Service, USFWS = U.S. Fish and Wildlife Service, Corps = U.S. Army Corps of Engineers, Oregon = State of Oregon Gener PGE = Portland General Electric.


WASHINGTON
WASH.
OREGON
Walla Walla
Walla Walla
R.
R.
COLUMBIA
RIVER
Umatilla R.
Pendleton
Grande
Ronde
Wallowa R.
La Grande
Powder R.
PORTLAND
The Dalles
Sandy R.
Clackamas R.
River
Willamette
River
Salem
Santiam R.
Metolius R.
Crooked River
McKenzie R.
Eugene
Bend
Deschutes
OREGON
1
2
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24
25
26

Map No.	Facility	Map No.	Facility
1	Klaskanine	14	Stayton Pond
2	Big Creek	15	Roaring River
3	Gnat Creek	16	S. Santiam
4	Sandy	17	Marion Forks
5	Wakeena Pond	18	Metolius
6	Bonneville	19	Wizard Falls
7	Cascade	20	Round Butte
8	OxBow	21	McKenzie
9	Hood River	22	Leaburg
10	Eagle Creek	23	Dexter Pond
11	Oak Springs	24	Oakridge
12	Salem Pond	25	Fall River
13	Aumsville Pond	26	Wallowa

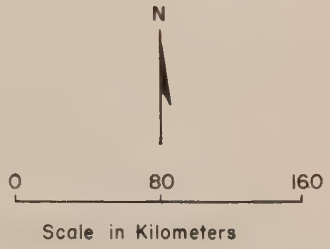

N
0
80
160
Scale in Kilometers

Figure 8.—Map of locations of Columbia Basin-Oregon salmonid rearing facilities, 1960-76.

Table 20.—Migrant releases of chinook and coho salmon—Columbia Basin-Oregon[1] (in thousands).

Release year	Fall chinook		Spring chinook		Summer chinook		Coho	
	Number	Pounds[2]	Number	Pounds	Number	Pounds	Number	Pounds
1960	34,585.9	99.1	6,017.4	168.3	0.0	0.0	3,545.8	156.6
1961	15,737.3	78.1	3,815.6	144.6	0.0	0.0	5,926.6	266.7
1962	15,035.9	57.5	3,031.9	128.8	0.0	0.0	7,814.9	413.9
1963	17,396.8	93.1	7,061.5	272.0	0.0	0.0	7,320.0	382.3
1964	26,171.5	174.8	9,430.6	312.6	0.0	0.0	8,294.8	437.3
1965	19,999.9	141.3	4,314.8	173.6	0.0	0.0	6,763.3	390.4
1966	17,988.3	174.3	8,272.0	363.1	0.0	0.0	6,730.6	394.7
1967	21,365.0	193.9	9,162.6	419.0	0.0	0.0	8,699.2	471.6
1968	22,709.6	270.6	8,576.8	554.5	0.0	0.0	7,037.5	411.5
1969	22,491.1	225.3	4,256.6	334.4	0.0	0.0	7,235.1	480.8
1970	32,901.2	358.9	6,975.9	683.2	0.0	0.0	6,719.1	419.6
1971	33,583.9	276.0	3,140.9	288.3	0.0	0.0	6,087.4	397.6
1972	32,185.0	341.9	4,122.2	356.0	0.0	0.0	11,731.4	814.5
1973	32,583.3	371.6	5,514.3	609.0	0.0	0.0	7,917.6	481.7
1974	33,317.2	359.9	3,722.6	321.0	0.0	0.0	8,117.3	482.9
1975	31,444.4	372.6	6,246.2	498.5	6.2	0.2	8,293.7	575.6
1976	40,681.6	525.7	4,810.5	439.8	62.8	2.2	9,234.7	599.6
Total	450,177.9	4,114.6	98,472.4	6,066.7	69.0	2.4	127,469.0	7,577.3

[1] Derived from Wahle et al. (1975) prior to 1974, Oregon Department of Fish and Wildlife release records, and U.S. Fish and Wildlife Service hatchery annual reports.

[2] 1 lb = 0.454 kg.

Table 21.—Migrant releases of chum salmon and sea-run cutthroat trout—Columbia Basin-Oregon[1] (in thousands).

Release year	Chum		Winter steelhead		Summer steelhead		Sea-run cutthroat	
	Number	Pounds[2]	Number	Pounds	Number	Pounds	Number	Pounds
1960	0.0	0.0	388.8	61.0	17.4	1.6	1.2	1.3
1961	12.8	0.1	307.7	27.4	63.1	6.9	9.0	1.8
1962	314.6	0.6	1,096.9	72.8	0.0	0.0	9.7	3.1
1963	280.9	0.4	746.2	45.9	70.4	6.6	6.5	1.9
1964	0.0	0.0	695.0	62.3	136.0	13.2	0.0	0.0
1965	0.0	0.0	758.2	75.2	59.0	6.4	1.0	0.3
1966	315.4	2.0	854.0	89.4	153.0	22.6	0.0	0.0
1967	372.0	2.8	1,004.9	96.6	114.9	12.2	7.5	2.4
1968	135.0	0.5	980.9	86.1	390.3	38.5	0.0	0.0
1969	82.6	0.2	883.0	87.0	530.6	59.8	0.0	0.0
1970	0.0	0.0	712.5	89.3	456.2	63.9	1.2	3.9
1971	0.0	0.0	748.1	73.0	441.7	64.3	7.0	1.8
1972	0.0	0.0	887.8	113.4	759.0	126.5	13.7	3.4
1973	0.0	0.0	824.4	123.2	1,009.1	175.3	8.5	2.4
1974	0.0	0.0	1,048.8	137.7	998.5	132.7	0.0	0.0
1975	0.0	0.0	849.9	125.9	876.6	135.8	34.1	11.1
1976	0.0	0.0	949.1	127.1	1,011.8	191.2	40.9	11.3
Total	1,513.3	6.6	13,736.2	1,493.3	7,087.6	1,057.5	140.3	44.7

[1] Derived from Wahle et al. (1975) prior to 1974, Oregon Department of Fish and Wildlife release records, and U.S. Fish and Wildlife Service hatchery annual reports.

[2] 1 lb = 0.454 kg.

some of these are voluntarily funded by county governments or private industry, most were constructed and are supported as compensation for loss of fish spawning areas due to construction of dams and other water related projects. Coleman NFH, operated by the USFWS, was built in 1942 in conjunction with Shasta Dam and the Central Valley Project which blocked salmonid access to a large area of the Sacramento River drainage. The Trinity River and Nimbus hatcheries were both built by the Bureau of Reclamation to compensate for construction of the Trinity Dam and the Folsom and Nimbus Dams, respectively. Additionally, Iron Gate and Mokelumne are funded by power companies and the Feather Hatchery is supported by the California Departm Water Resources.

HATCHERY TRENDS

Hatchery Numbers

Since the first Pacific coast hatchery was built i rearing of salmon and steelhead trout has bec business, both in efforts and dollars expended fits derived. In the late 1800's and early 190

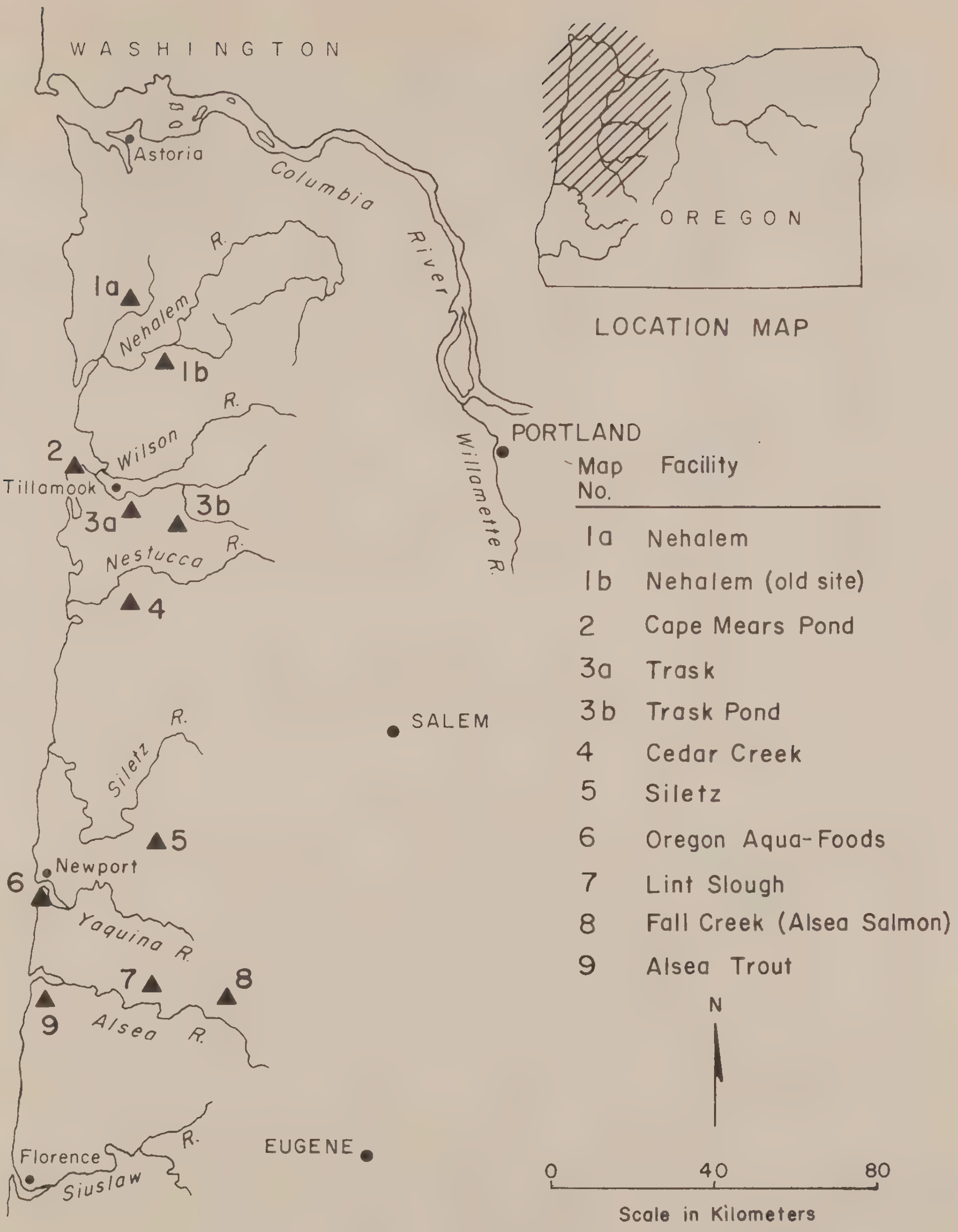
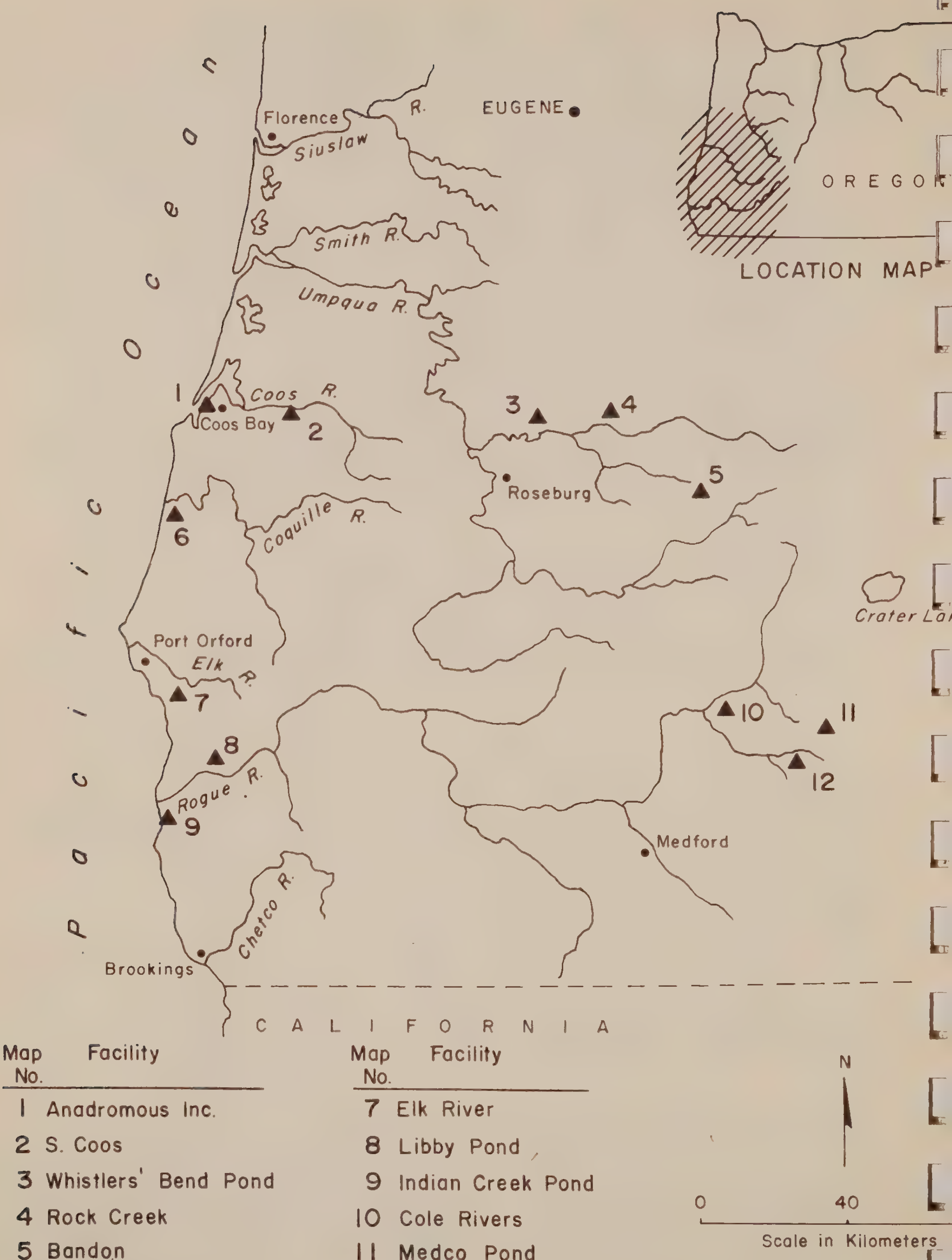

WASHINGTON
Astoria
Columbia River
Nehalem R.
Wilson R.
Tillamook
Nestucca R.
Siletz R.
Newport
Yaquina R.
Alsea R.
Florence
Siuslaw R.
Willamette R.
PORTLAND
SALEM
EUGENE
1a
1b
2
3a
3b
4
5
6
7
8
9
OREGON
LOCATION MAP
Map No.
Facility
1a Nehalem
1b Nehalem (old site)
2 Cape Mears Pond
3a Trask
3b Trask Pond
4 Cedar Creek
5 Siletz
6 Oregon Aqua-Foods
7 Lint Slough
8 Fall Creek (Alsea Salmon)
9 Alsea Trout
N
0
40
80
Scale in Kilometers

Figure 9.—Map of locations of northern Oregon coastal salmonid rearing facilities, 1960-76.

ederal, and local government agencies and pri-
erprises rushed to build hatcheries. Though
ny of these early efforts ended in failure for various
there were 72 hatcheries and rearing ponds on
in 1929. The total releases from all early hatch-
s through 1928 were in excess of 12 billion fry and 1
ion fingerlings and yearlings (Cobb 1931).

en 1929 and the early 1940's, there was a decline
mber of active hatcheries due in part to the De-
ssion and World War II. All but 3 of the 18 U.S. Bureau of Fisheries (now U.S. Fish and Wildlife Service) hatcheries were closed, replaced, or turned over for State operation. The Alaskan, Canadian, and California facilities in production in 1929 were also closed, or in a few cases, converted to trout culture. Only the State hatcheries of Washington and Oregon did not decline significantly in number. Many of those built in these two States prior to 1929 are currently in production. Additionally, new facilities built in the Washington coastal region in the 1930's are still in operation today.



Pacific Ocean
Florence
Siuslaw R.
EUGENE
Smith R.
Umpqua R.
Coos R.
Coos Bay
1
2
3
4
5
Roseburg
6
Coquille R.
Port Orford
Elk R.
7
8
Rogue R.
9
Chetco R.
Brookings
CALIFORNIA
Medford
10
11
12
Crater La
OREGO
LOCATION MAP
N
0
40
Scale in Kilometers

Map No.	Facility	Map No.	Facility
1	Anadromous Inc.	7	Elk River
2	S. Coos	8	Libby Pond
3	Whistlers' Bend Pond	9	Indian Creek Pond
4	Rock Creek	10	Cole Rivers
5	Bandon	11	Medco Pond
6	Hemlock Meadows	12	Butte Falls

Figure 10.—Map of locations of southern Oregon coastal salmonid rearing facilities, 1960-76.

Table 22.—Anadromous fish rearing facilities—Oregon coastal, 1960-76.

Facility	General location	Operating agency[1,3]	Species reared during year span[2]	Anadromous releases in 1976	Year anadromous operation began	Funding agency[3]
Hatcheries						
sea	Philomath	ODFW (OGC)	sh, src (fc, co)	Yes	1937	Oregon
adromous Inc.	Coos Bay	Private	co	Yes	1975	Private
ndon	Bandon	ODFW (OGC)	sh, src (fc, co)	Yes	1924	Oregon
Butte Falls	Butte Falls	ODFW (OGC)	sc, sh	No	1916	Oregon
Cedar Creek	Hebo	ODFW (OGC)	fc, sc, sh, src (co)	Yes	1935	Oregon
le Rivers	McLeod	ODFW (OGC)	sc, sh	Yes	1972	Corps
k River	Port Orford	ODFW (FCO)	fc (co, sh)	Yes	1969	Oregon, Fed
Fall Creek	Alsea	ODFW (FCO)	fc, co (sc)	Yes	1952	Oregon
Nehalem	Nehalem	ODFW (FCO)	fc, co, sh (sc, ch)	Yes	[4]1968	Oregon
egon Aqua Foods	Newport	Private	fc, sc, co	Yes	1972	Private
ck Creek	Idleyld Park	ODFW (OGC)	sc, co, sh (fc)	Yes	1922	Oregon
letz River	Nashville	ODFW (FCO)	co (fc, sc)	Yes	1937	Oregon
South Coos	Coos Bay	ODFW (FCO)	co	No	1900	Oregon
Trask River	Tillamook	ODFW (FCO)	fc, sc, co (ch)	Yes	1914	Oregon
ing ponds						
pe Mears	Tillamook	ODFW (OGC)	fc	No	1967	Oregon
emlock Meadows	Roseburg	ODFW (OGC)	sh	No	1964	Oregon
Indian Creek	Shady Cove	ODFW (OGC)	co	No	1969	Oregon
Libby	Gold Beach	ODFW (OGC)	fc	No	1965	Oregon
nt Slough	Waldport	ODFW (OGC)	fc, co	No	1963	Oregon
edco	Prospect	ODFW (OGC)	sh	No	1962	Oregon
Whistlers Bend	Roseburg	ODFW (OGC)	fc	No	1967	Oregon

[1] Current agency with premerger agency in parentheses.

= fall chinook salmon, sc = spring chinook salmon, co = coho salmon, sh = steelhead trout, src = sea-run cutthroat trout, ch = chum on.

[3] ODFW = Oregon Department of Fish and Wildlife, FCO = Fish Commission of Oregon, OGC = Oregon Game Commission, Oregon = State of Oregon General Fund, Corps = U.S. Army Corps of Engineers, Fed = Federal Fund 89-304.

atchery moved to this location in 1968. It was constructed on the original site in 1918.

Table 23.—Migrant releases of chinook and coho salmon and steelhead and sea-run cutthroat trout—Oregon coastal[1] (in thousands).

Release year	Fall chinook		Spring chinook		Coho		Winter steelhead		Summer steelhead		Sea-run cutthroat	
	Number	Pounds[2]	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
1960	304.5	1.0	98.4	13.9	1,001.7	68.0	216.3	16.7	79.2	8.5	154.2	41.5
1961	358.1	2.6	137.2	15.6	1,390:0	89.2	263.5	28.8	173.4	31.5	173.5	50.0
1962	340.7	1.1	251.7	42.2	2,810.7	167.8	294.1	33.2	368.3	32.3	280.4	74.1
1963	677.2	7.5	212.4	35.7	2,773.6	171.7	299.6	36.8	292.2	23.8	126.9	45.3
1964	359.5	1.9	330.8	39.6	1,960.6	121.2	511.0	60.8	334.9	28.0	173.5	53.4
1965	77.8	0.9	190.4	23.8	2,172.3	129.0	573.1	57.4	268.4	27.0	114.2	35.9
1966	806.5	9.2	138.6	14.9	2,105.0	138.7	617.1	90.4	205.9	22.6	163.5	51.1
1967	890.7	10.7	265.3	39.9	2,432.8	156.8	606.5	79.2	299.2	43.9	200.0	65.5
1968	2,706.7	42.6	259.7	39.9	3,229.0	193.8	869.0	127.2	337.6	53.5	152.7	45.2
1969	1,599.1	61.7	175.6	27.4	3,407.9	235.8	935.6	136.3	477.2	73.3	131.2	45.5
1970	2,880.5	107.5	417.8	56.1	3,303.3	219.2	1,213.1	173.4	529.5	90.6	195.8	60.8
1971	2,138.8	96.4	412.5	57.8	3,834.9	261.3	1,292.5	206.3	457.6	74.5	192.8	53.9
1972	1,669.2	103.6	378.4	57.2	3,528.3	244.1	1,378.5	211.4	460.6	71.7	206.3	55.0
1973	2,143.4	97.5	408.7	64.9	3,926.6	266.2	1,285.3	183.5	445.8	81.6	244.0	70.8
1974	2,631.9	162.4	534.5	83.3	4,287.7	273.5	1,187.4	159.0	421.6	73.0	204.3	61.2
1975	1,924.6	120.1	657.7	106.3	4,196.4	307.8	1,277.3	196.5	384.7	77.3	106.0	51.5
1976	1,902.2	166.4	417.3	57.5	5,217.7	349.2	1,279.3	206.8	317.9	53.3	220.1	64.2
Total	23,411.4	993.1	5,287.0	776.0	51,578.5	3,393.3	14,099.2	2,003.7	5,854.0	866.4	3,129.4	924.9

[1] Derived from Wahle et al. (1975) prior to 1974 and Oregon Department of Fish and Wildlife hatchery release reports.

[2] 1 lb = 0.454 kg.

n the late 1940's salmon and steelhead trout popula- ng the Pacific coast began to decline because of d fishing pressure, loss of habitat, and fish sage problems at newly constructed hydroelectric jects. This decline stimulated increased hatchery pro- efforts. The Lower Columbia River Develop- ogram, of the then Bureau of Commercial Fisheries, funded the construction of a number of hatcheries, including Willard, Kalama Falls, Abernathy, and Klickitat, and the renovation of other facilities already in operation. Several new hatcheries were built in California including the Coleman NFH constructed by the U.S. Bureau of Reclamation for the USFWS to replace two facilities inundated by the filling of Shasta Lake.

Table 24.—Anadromous fish rearing facilities—California, 1960-76.

Facility	General location	Operating agency[1]	Species reared during year span[2]	Anadromous releases in 1976	Year anadromous operation began	Fundin
Hatcheries						
Coleman	Anderson	USFWS	fc, sh (co)	Yes	1942	USFWS
Crystal Lake	Burney	CDFG	sh (co)	Yes	1948	CDFG
Darrah Springs	Paynes Creek	CDFG	co (fc)	Yes	1954	CDFG
Feather River	Oroville	CDFG	fc, sc, sh	Yes	1967	CDWR
Iron Gate	Hornbrook	CDFG	fc, sc, co, sh	Yes	1966	CDFG, PP
Mad River	Blue Lake	CDFG	fc, co, sh	Yes	1971	CDFG,
Merced rearing facility	Snelling	CDFG	fc, co	Yes	1973	CDFG
Mokelumne	Clements	CDFG	fc, sh	Yes	1964	EBMU
Nimbus	Rancho Cordova	CDFG	fc, sh	Yes	1955	BR
Prairie Creek	Orick	Humbolt County	fc, co, sh, src	Yes	1928	Humbolt C
Trinity	Lewiston	CDFG	fc, sc, co, sh	Yes	1963	BR
Ponds						
Cochran Creek	Eureka	Fish Action Council Humbolt County	fc, co	Yes	1968	CDFG
Pacific Lumber Co.	Scotia	Pacific Lumber Co., CDFG	sh	No	1972	Pacific
Talmadge	Talmadge	Sports Club, CDFG	sh	Yes	1972	Mendoc

[1] USFWS = U.S. Fish and Wildlife Service, CDFG = California Department of Fish and Game, CDWR = California Department of Water Re PP&L = Pacific Power and Light, NMFS = National Marine Fisheries Service (Anadromous Fish Act), EBMUD = East Bay Municipal trict, BR = Bureau of Reclamation.

[2] fc = fall chinook salmon, sc = spring chinook salmon, co = coho salmon, sh = steelhead trout, src = sea-run cutthroat trout.

As water-use projects continued to block access to anadromous salmonid spawning and rearing areas, it was necessary to build hatcheries to compensate for the resulting loss of fish. Some of these hatcheries include Trinity River and Iron Gate in California, Chelan PUD and the two Cowlitz hatcheries in Washington, and Round Butte in Oregon.

The 1960's saw the re-entry of Alaska and British Columbia into the salmonid propagation field. Again, this was necessitated by decline in fish stocks and the decreases in catches in those two areas. Idaho was also forced into the hatchery salmon and steelhead trout program because of the adverse effects of dams on the Columbia and Snake Rivers.

In 1960 there were 72 hatcheries, pens, and saltwater net pens producing salmon and steelhead trout on the coast (Fig. 12). This was approximately the same number as in 1929. The number increased to a maximum of 154 in 1976, over a twofold gain. In all, 192 facilities reared anadromous fish for at least 1 yr on the Pacific coast during the 17-yr span ending in 1976.

Species Reared

One of the major trends in hatchery production of salmonids has been the shift in emphasis placed on rearing different species of salmon and anadromous trout. Prior to 1929, of the over 12 billion fry and 1 billion fingerlings and yearlings released, almost half were sockeye salmon. In 1910 alone there were almost 400 million sockeye salmon fry released (Cobb 1931).

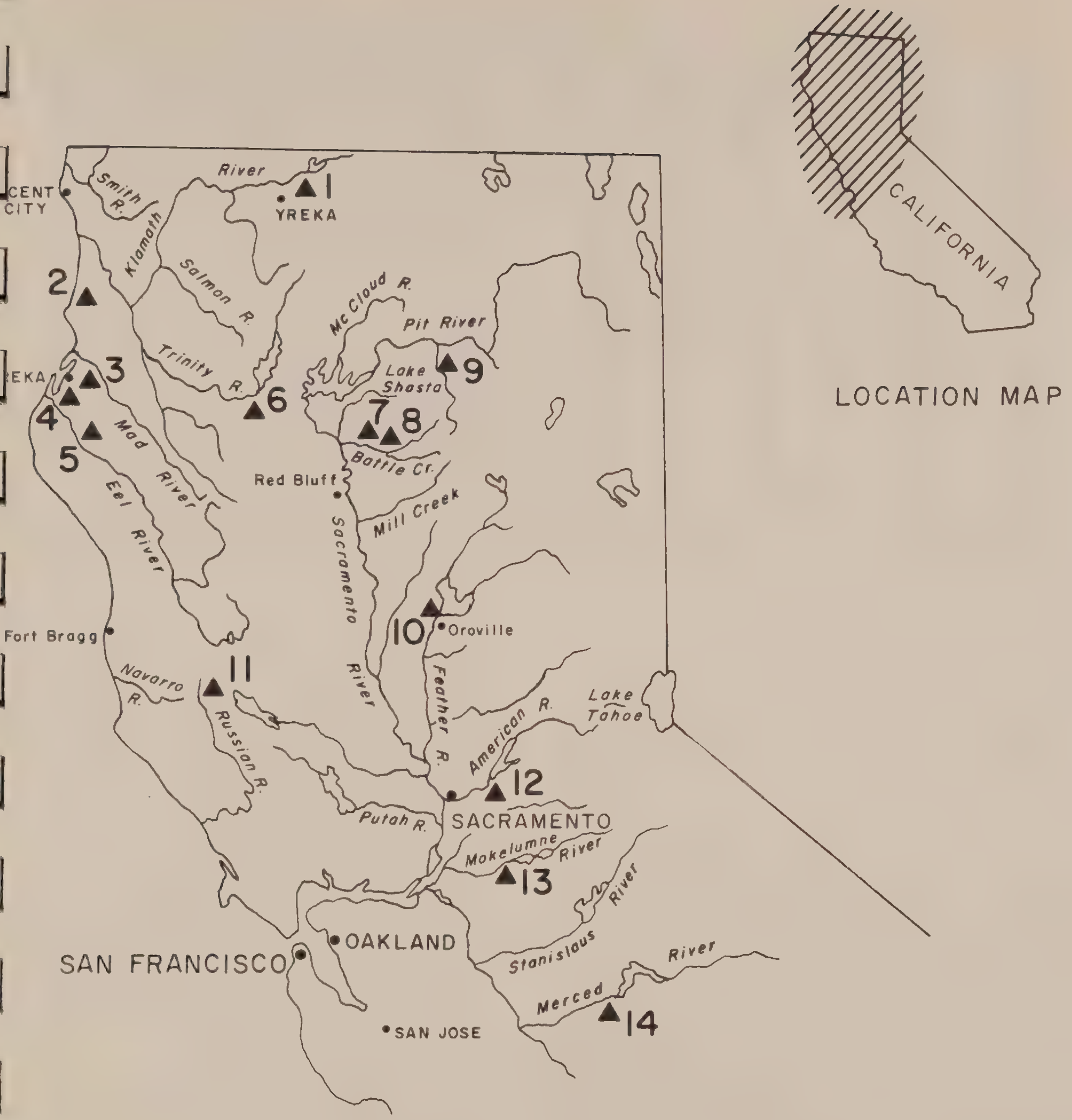
With the closing of large Alaska and British Columbia sockeye salmon stations in the 1920's and 1930's species emphasis changed. For the 17 yr since 1960, the major species reared have been chinook salmon, coho salmon, and steelhead trout (Fig. 13). The sockeye sal leases had declined to only 3 million in 1960 with these coming from Leavenworth NFH on the Columbia River in Washington. Since 196 Leavenworth terminated its sockeye salmon p only two releases of this species have been made to 27,000 fish.

Rearing Trends

One of the major changes in hatchery operati been the switch from releasing unfed fry to r salmon and steelhead trout after a period of rea the late 1800's and early 1900's, the standard hat practice was to release fish soon after the eggs h when the yolk sac had been absorbed. The small that were retained and fed were kept as cur Although no difficulty was experienced raising thes the added expense of fish food as well as the ina rearing space at the hatcheries precluded genera tion of rearing programs.

As previously stated, a few fish culturists, includi D. Hume from Oregon, disagreed with the practi leasing unfed fry. It was their belief that unfed ill equipped to survive competition with wild fis predators and the increased survival and contrib obtained from releasing larger fish would outwe additional expense of rearing. Over the years proven to be true and today almost all anadromou are fed for a period of time before they are rele

The early efforts of rearing fish depended on di on ground meat and fish products. Liver, sple salmon carcasses were common ingredients, su mented with various grains and meals. These di not very efficient and were messy and time consu


LOCATION MAP
CALIFORNIA
CENT
CITY
Smith R.
River
1
YREKA
Klamath
Salmon R.
2
EKA
3
4
5
Trinity R.
6
Mad River
Eel River
McCloud R.
Pit River
9
Lake Shasta
7
8
Battle Cr.
Red Bluff
Mill Creek
Sacramento River
10
Oroville
Feather R.
Fort Bragg
Navarro R.
11
Russian R.
American R.
Lake Tahoe
12
SACRAMENTO
Putah R.
Mokelumne River
13
Stanislaus River
SAN FRANCISCO
OAKLAND
Merced River
14
SAN JOSE

	Facility	Map No.	Facility
	Iron Gate	8	Darrah Springs
	Prairie Creek	9	Crystal Lake
	Mad River	10	Feather River
	Cochran Creek	11	Talmadge Pond
	Pacific Lumber Co. Pond	12	Nimbus
	Trinity River	13	Mokelumne Facility
	Coleman	14	Merced River

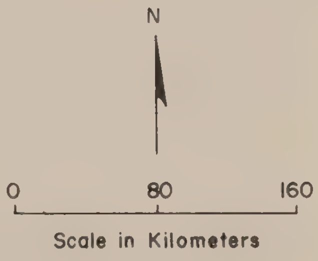

N
0
80
160
Scale in Kilometers

Figure 11.—Map of locations of northern California salmonid rearing facilities, 1960-76.

Table 25.—Migrant releases of chinook and coho salmon and steelhead and sea-run cutthroat trout—California[1] (in thousands).

Release	Fall chinook		Spring chinook		Coho		Winter steelhead		Summer steelhead		Sea-run cutthroat	
year	Number	Pounds[2]	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
1960	5,386.6	125.5	0.0	0.0	0.0	0.0	315.1	16.4	0.0	0.0	0.0	0.0
1961	34,085.5	226.6	0.0	0.0	58.0	5.9	518.1	49.7	0.0	0.0	0.0	0.0
1962	7,293.3	140.7	0.0	0.0	364.0	32.0	187.3	18.6	0.0	0.0	1.9	0.4
1963	19,862.4	205.5	0.0	0.0	498.9	43.9	72.3	10.4	0.0	0.0	0.0	0.0
1964	10,161.7	148.7	300.0	10.4	499.3	43.9	1,163.1	146.3	0.0	0.0	2.7	0.9
1965	6,529.8	161.8	224.5	12.8	1,097.4	81.8	736.7	74.6	0.0	0.0	6.8	1.1
1966	11,015.7	171.6	0.0	0.0	747.2	86.2	2,436.2	327.1	0.0	0.0	10.7	2.6
1967	7,748.4	123.9	0.0	0.0	1,264.6	87.9	2,027.0	281.3	0.0	0.0	7.6	2.0
1968	14,157.1	163.0	528.6	41.3	1,821.0	130.1	2,129.7	314.3	0.0	0.0	5.3	1.3
1969	17,442.9	193.7	673.4	57.4	1,448.1	123.1	1,818.8	274.8	0.0	0.0	3.1	1.3
1970	16,808.6	302.9	120.8	14.8	1,152.1	93.0	2,169.8	318.5	18.7	2.2	55.0	3.8
1971	34,206.1	475.3	569.9	66.5	1,245.5	112.1	3,618.9	399.3	133.6	18.5	0.0	0.0
1972	37,275.7	494.3	247.3	24.8	1,664.5	153.3	4,340.6	527.9	212.2	26.9	0.8	0.1
1973	21,707.1	387.6	507.6	64.5	1,161.7	79.3	2,916.7	344.4	37.1	3.8	1.0	0.6
1974	22,667.0	418.4	482.9	47.2	802.8	54.4	3,081.1	348.7	141.6	27.2	0.0	0.0
1975	27,837.6	456.6	303.2	32.9	1,771.1	151.0	2,524.3	298.8	0.0	0.0	6.1	0.8
1976	24,444.4	471.2	888.5	115.8	1,046.6	90.4	2,948.5	416.2	77.8	12.6	4.3	1.2
Total	318,629.9	4,667.3	4,846.7	488.4	16,642.8	1,368.3	33,004.2	4,167.3	621.0	91.2	105.3	16.1

[1] Derived from Wahel et al. (1975) prior to 1974, U.S. Fish and Wildlife Service hatchery annual reports, and California hatchery records.

[2] 1 lb = 0.454 kg.

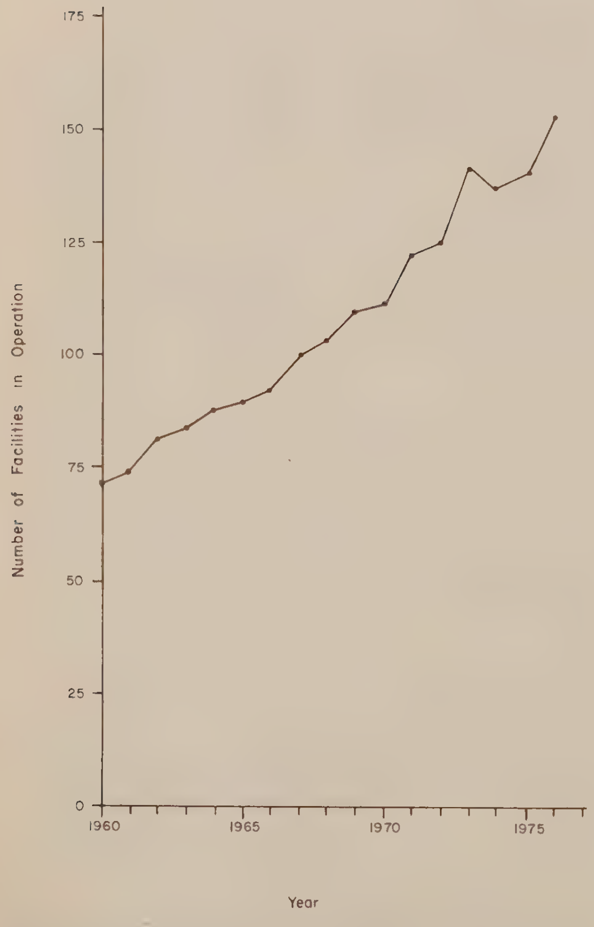


Figure 12.—Number of Pacific coast salmonid rearing facilities releasing anadromous salmonids by year, 1960-76.

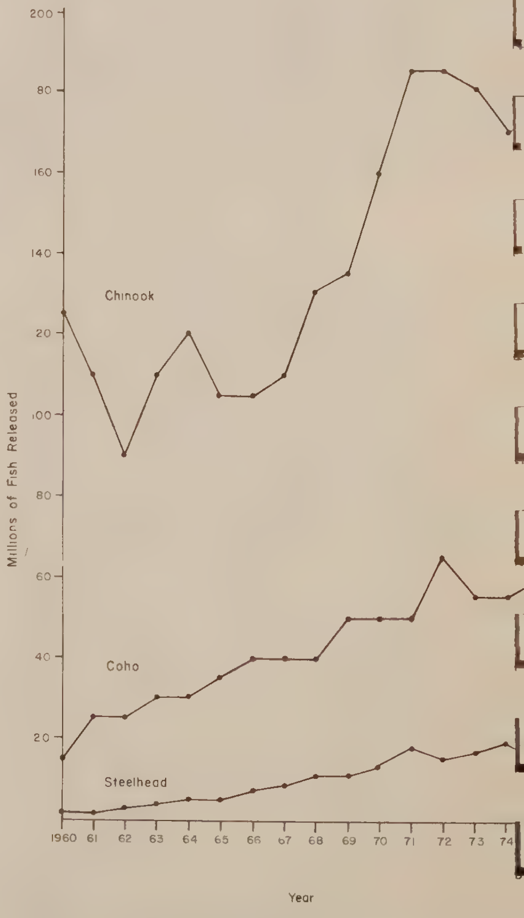


Figure 13.—Numbers of Pacific coast releases of chinook salmon and steelhead trout (in millions).

pare. In the 1950's, conversion ratios as low as 5.6 lb kg) of food fed per pound (0.45 kg) of weight gained orted from the ground-meat base diets used at CO hatcheries. At most hatcheries today, less an 2 lb (0.91 kg) of food are required for a 1 lb (0.45 kg) n in weight. Another disadvantage of the meat diets pread of bacteria and viral diseases, to young fish ts that included salmon carcasses. Although the ts did have disadvantages, they still allowed larger e reared.

l developments in the late 1950's had important ects on rearing practices. Improved pasteurization thods were developed to treat salmon viscera, an im- component of many meat based diets. This pro- used to kill disease-causing organisms that uld otherwise have affected the young fish. Commer- l, dry, pelletized trout diets received much attention ntally as a salmon diet. Few of the standard ds showed promise and all required meat diets to used while the fish started feeding.

n 1959, after many years of experimentation, the FCO eding Oregon moist pellets (OMP) to fish at 16 of mon hatcheries. The OMP diet, developed joint- by the FCO and Oregon State University scientists h funds supplied by the U.S. Bureau of Commercial (now National Marine Fisheries Service), was a eakthrough in the area of hatchery nutrition. This easi- fed diet does not require any preparation at the and is readily accepted by the fish. It consists of ation of cereals, fish meals, fish oils, dried skim k, and vitamin supplements. Fish fed this diet have wn, in almost all cases, better survival and contribu- he fishery than fish fed old ground meat type ublou et al. 1959, Hublou 1963). Development of OMP has opened the way for other types of diets in- ding the Abernathy dry pellet developed at Abernathy Cultural Development Center. These new diets ade hatcheries biologically and economically sible ventures.

Time of Release

One of the most interesting trends of hatchery pro- over the last 17 yr has been the change in release migrant coho, spring chinook, and fall chinook mon. Until the early 1960's hatcheries emphasized of fish liberated. It was common for a hatchery more eggs than could be reared to migrant size. fish grew and crowding occurred, fish in excess of tchery capacities were released. Out of an egg-take of million fall chinook salmon eggs in 1959, Spring FH produced only 7.8 million migrants in May of 0. The other 5.8 million were thinned out 3 mo earlier ahle et al. 1975). The average size for all species of mi- lmon released from Pacific coast rearing facili- 60 was 88 fish/lb (5.2 g/fish) (Fig. 14a). Fall chi- ok salmon, reared for 5 or 6 mo, averaged 211 fish/lb 29 g/fish) (Fig. 14b). Spring chinook and coho salm- ed for an average of 20 mo, both averaged 33 13.8 g/fish) (Fig. 14c,d).

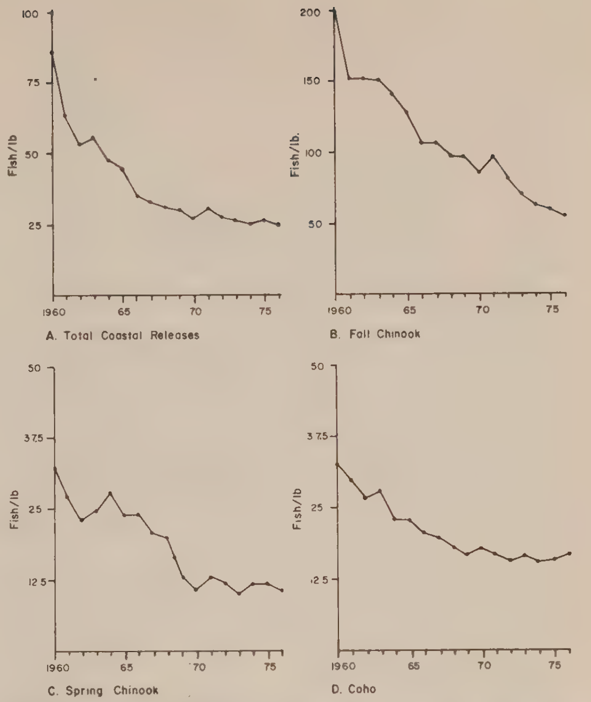


Figure 14.—Average size of various species of Pacific coast anadromous salmonid releases (all species combined), 1960-76. (1 lb equals 0.454 kg.)

In the early 1960's, a trend developed away from maximizing numbers at hatcheries. Instead, the philosophy of raising less fish to a larger size began to gain acceptance among the fish rearing agencies. Marking experiments showed that these larger fish had better survival and contribution to the fisheries (Senn and Noble 1968; Johnson 1970; Wallis[7]; Senn et al.[8]; Washington Department of Fisheries[9]). Numbers of migrant fish released actually declined slightly from 1960 to 1962 (Fig. 15) even though the number of facilities increased (Fig. 12). While migrant numbers held fairly constant from 1960 to 1976, the number of migrant pounds increased almost six times (Fig. 15). In 1976, fall chinook salmon smolts averaged 59 fish/lb (7.7 g/fish) (Fig. 14b). Spring chinook and coho salmon showed similar size change, going from approximately 32 fish/lb (4.2 g/fish) to 11 fish/lb (41.2 g/fish) and from 33 fish/lb (13.6) to 17 fish/lb (26.7 g/fish), respectively (Fig. 14c,d). During this time, the average size for all species combined went from 88 fish/lb (5.2 g/fish) to 26 fish/lb (17.5 g/fish) (Fig. 14a).

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[7] Wallis, J. 1968. Recommended time, size and age for release of hatchery-reared salmon and steelhead trout. Fish. Comm. Oreg., Clackamas, Proc. Rep., 61 p.

[8] Senn, H. G., R. C. Hager, and C. W. Hopley, Jr. 1975. The effects of experimentally varying the size and time of release of hatchery-reared coho salmon. Unpubl. manuscr., 14 p. Washington Department of Fisheries, Olympia, Wash.

[9] Washington Department of Fisheries. 1977. 1972-brood Toutle River coho time/size at release study. Unpubl. manuscr., 16 p. Washington Department of Fisheries, Olympia, Wash.

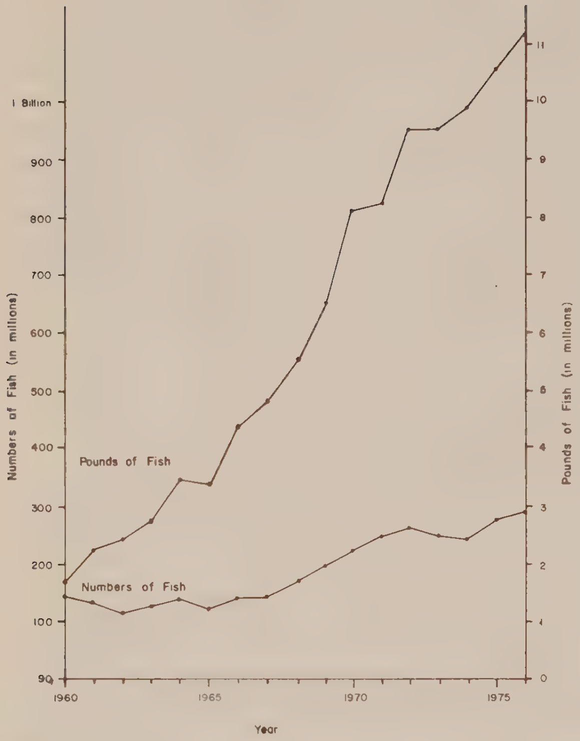

Figure 15.—Total Pacific coast migrant anadromous salmonid releases (all species combined), 1960-76. (1 lb equals 0.454 kg.)

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Appendix Table 1.—Pacific coast anadromous fish rearing facilities.

Facility name	Region	Facility name	Region
te Fish Hatchery Park Drive leen, WA 98520	Washington coastal and Puget Sound	Big White Salmon Rearing Pond c/o Spring Creek National Fish Hatchery Underwood, WA 98651	Columbia Basin-Washington
almon Cultural nt Center Aberna[illegible]hy Road view, WA 98632	Columbia Basin-Washington	Blue Slough Rearing Pond (Closed) c/o Washington Dept. of Game 600 N. Capitol Way Olympia, WA 98504	Washington coastal and Puget Sound
Rearing Pond eek State Fish Hatchery 1, Box 274A amet, WA 98612	Columbia Basin-Washington	Bonneville Fish Hatchery P.O. Box 262 Bonneville, OR 97008	Columbia Basin-Oregon
tchery Route 2, Box 52 nath, OR 97370	Oregon coastal	Bowman's Bay Rearing Ponds (Closed) c/o Washington Dept. of Fisheries Rm 115, Gen. Admin. Bldg. Olympia, WA 98504	Washington coastal and Puget Sound
Inc. 2012 Island, OR 97054	Oregon coastal	Butte Falls Fish Hatchery 580 Fish Lake Road Butte Falls, OR 97522	Oregon coastal
out Hatchery 107 gton, WA 98223	Washington coastal and Puget Sound	Cape Mears (Closed) c/o Oregon Dept. of Fish and Wildlife P.O. Box 3503 Portland, OR 97208 ATTN: Mr. Jefferies	Oregon coastal
ville Pond Rd S.E. R 97325	Columbia Basin-Oregon	Capilano Hatchery 4500 Capilano Park Road North Vancouver, British Columbia	British Columbia
on Fish Hatchery 195 97411	Oregon coastal	Carson National Fish Hatchery Carson, WA 98610	Columbia Basin-Washington
aby Rearing Pond Box 102 A 98283	Washington coastal and Puget Sound	Cascade Fish Hatchery Star Route, Box 526 Bonneville, OR 97008	Columbia Basin-Oregon
Center Mariculture 03 WA 98527	Washington coastal and Puget Sound	Cedar Creek Fish Hatchery Route 1, Box 9 Hebo, OR 97122	Oregon coastal
Trout Hatchery 1, Box 274A amet, WA 98612	Columbia Basin-Washington	Chambers Creek Trout Hatchery c/o South Tacoma Hatchery 7723 Phillips County Road, S.W. Tacoma, WA 98498	Washington coastal and Puget Sound
Fish Hatchery com Falls Park ngham, WA 98225	Washington coastal and Puget Sound	Chelan PUD Trout Fish Hatchery Star Route Chelan, WA 98816	Columbia Basin-Washington
h Hatchery 594 ia, OR 97103	Columbia Basin-Oregon	Cochran Creek Rearing Pond c/o Humbolt Fish Action Council P.O. Box 154 Eureka, CA 95501	California
h Hatchery cum Beach, British Columbia	British Columbia		

Coleman National Fish Hatchery Route 1, Box 2105 Anderson, CA 96007	California
Cole Rivers Fish Hatchery Laurelhurst Road Trail, OR 97541	Oregon coastal
Columbia Basin State Fish Hatchery Route 2, Box 333C Moses Lake, WA 98837	Columbia Basin-Washington
Coos River State Hatchery (Closed) c/o Oregon Dept. of Fish and Wildlife P.O. Box 3503 Portland, OR 97208 ATTN: Mr. Jefferies	Oregon coastal
Cowlitz Salmon Hatchery 2284 Spencer Road Salkum, WA 98582	Columbia Basin-Washington
Cowlitz Trout Hatchery Salkum, WA 98582	Columbia Basin-Washington
Crystal Lake Hatchery P.O. Box 1088 Petersburg, AK 99833	Alaska
Crystal Lake Hatchery Route 2, Box 1113 Burney, CA 96013	California
Darrah Springs Hatchery P.O. Box 8 Paynes Creek, CA 96075	California
Decker Flats Rearing Pond P.O. Box 1196 Salmon, ID 83467	Columbia Basin-Idaho
Deschutes Rearing Pond c/o Washington Dept. of Fisheries Rm 115, Gen. Admin. Bldg. Olympia, WA 98504	Washington coastal and Puget Sound
Dexter Rearing Pond General Delivery Lowell, OR 97456	Columbia Basin-Oregon
Domsea Farms Aquaculture Salt water-P.O. Box 372 Manchester, WA 98353 Fresh water-510 Washington Bremerton, WA 98310	Washington coastal and Puget Sound
Dungeness Salmon Hatchery Route 6, Box 983 Sequim, WA 98383	Washington coastal and Puget Sound
Dworshak National Fish Hatchery P.O. Box 251 Ahsahka, ID 83520	Columbia Basin-Idaho
Eagle Hatchery Eagle, ID 83616	Columbia Basin-Idaho
Eagle Creek National Fish Hatchery Route 1, Box 610 Estacada, OR 97023	Columbia Basin-Oregon
Elk River Fish Hatchery Star Route, Box 150 Port Orford, OR 97465	Oregon coastal
Elokomin Salmon Hatchery Route 1, Box 300 Cathlamet, WA 98612	Columbia Basin-W
Entiat National Fish Hatchery Star Route, Box 410 Entiat, WA 98822	Columbia Basin-W
Fall Creek Hatchery (Alsea Salmon) Route 2, Box 47 Alsea, OR 97324	Oregon coastal
Falls River Fish Hatchery 15055 S. Century Drive Bend, OR 97701	Columbia Basin-O
Feather River Hatchery 5 Table Mt. Blvd. Oroville, CA 95965	California
Fire Lake Hatchery P.O. Box 488 Eagle River, AK 99577	Alaska
Garrison Spring Salmon Hatchery P.O. Box 94141 Fort Steilacoom, WA 98494	Washington coasta Puget Sound
George Adams Hatchery Rt. 5, Box 125 Shelton, WA 98584	Washington coasta Puget Sound
Gnat Creek Fish Hatchery Star Route 2 Clatskanie, OR 97016	Columbia Basin-O
Goldendale Trout Hatchery Route 2, Box 111 Goldendale, WA 98620	Columbia Basin-W
Gorst Creek Pond c/o Washington Dept. of Fisheries Rm 115, Gen. Admin. Bldg. Olympia, WA 98504	Washington coasta Puget Sound
Grays River Salmon Hatchery P.O. Box 768 Grays River, WA 98621	Columbia Basin-W
Green River Salmon Hatchery Route 1, Box 740 Auburn, WA 98002	Washington coasta Puget Sound
Green River Rearing Pond P.O. Box 96 Palmer, WA 98048	Washington coasta Puget Sound
Hagerman State Fish Hatchery Hagerman, ID 83332	Columbia Basin-Id
Halibut Cove Lagoon c/o F.R.E.D. Division P.O. Box 234 Homer, AK 99603	Alaska
Harrison Rearing Pond c/o Barnaby Rearing Pond P.O. Box 102 Rockport, WA 98283	Washington coasta Puget Sound
Hayden Creek Hatchery P.O. Box 25 Lemhi, ID 83465	Columbia Basin-Id

nlock Meadows Rearing Pond Closed) Oregon Dept. of Fish and Wildlife 503 R 97208 TTN: Mr. Jefferies	Oregon coastal
l Salmon Hatchery dspo, WA 98548	Washington coastal and Puget Sound
d River State Trout Hatchery Dept. of Fish and Wildlife . Box 3503 tland, OR 97208 Mr. Jefferies	Columbia Basin-Oregon
ian Creek Rearing Pond (Closed) Oregon Dept. of Fish and Wildlife 503 R 97208 ATTN: Mr. Jefferies	Oregon coastal
Hatchery Route CA 96044	California
quah Salmon Hatchery 55 VA 98027	Washington coastal and Puget Sound
lama Falls Salmon Hatchery na River Road VA 98625	Columbia Basin-Washington
skanine Fish Hatchery ox 764 R 97103	Columbia Basin-Oregon
ckitat Salmon Hatchery ute 2, Box 90 WA 98619	Columbia Basin-Washington
oskia National Fish Hatchery ute 1, Box 98-A oskia, ID 83539	Columbia Basin-Idaho
burg Fish Hatchery 01 Fish Hatchery Road OR 97401	Columbia Basin-Oregon
avenworth National Fish Hatchery ute 1, Box 123-A avenworth, WA 98826	Columbia Basin-Washington
r Salmon Hatchery 4 Lewis River Road odland, WA 98674	Columbia Basin- Washington
ing Pond (Closed) Dept. of Fish and Wildlife . Box 3503 tland, OR 97208 Mr. Jefferies	Oregon coastal
Slough Rearing Pond Oregon Dept. of Fish and Wildlife . Box 3503 OR 97208 Mr. Jefferies	Oregon coastal
Little Clam Bay Rearing Pond c/o Washington Dept. of Fisheries Rm 115, Gen. Admin. Bldg. Olympia, WA 98504	Washington coastal and Puget Sound
Little Port Walter Research Station c/o Auke Bay NMFS Fisheries Laboratory P.O. Box 155 Auke Bay, AK 99821	Alaska
Little White Salmon National Fish Hatchery P.O. Box 17 Cook, WA 98605	Columbia Basin-Washington
Lower Kalama Salmon Hatchery 1404 Kalama River Road Kalama, WA 98625	Columbia Basin-Washington
Lummi Indian Net Pens c/o Lummi Indian Tribal Enterprises Mr. Jim Ellis P.O. Box 309 Marietta, WA 98268	Washington coastal and Puget Sound
MacKay Hatchery MacKay, ID 83251	Columbia Basin-Idaho
Mad River Hatchery Route 1, Box 184 Arcata, CA 95521	California
Marion Forks Fish Hatchery Star Route, Box 71 Idanha, OR 97350	Columbia Basin-Oregon
McCall Hatchery P.O. Box 1021 McCall, ID 83638	Columbia Basin-Idaho
McKenzie Fish Hatchery 43863 Greer Drive Leaburg, OR 97401	Columbia Basin-Oregon
Medco Rearing Pond (Closed) c/o Oregon Dept. of Fish and Wildlife P.O. Box 3503 Portland, OR 97208 ATTN: Mr. Jefferies	Oregon coastal
Mendenhall Rearing Pond c/o Alaska Dept. of Fish and Game 210 Ferry Way Juneau, AK 99801 ATTN: Mr. Bethers	Alaska
Merced River Rearing Facility P.O. Box 94 Snelling, CA 95369	California
Metolius Hatchery (Closed) c/o Oregon Dept. of Fish and Wildlife P.O. Box 3503 Portland, OR 97208 ATTN: Mr. Jefferies	Columbia Basin-Oregon
Minter Creek Salmon Hatchery Route 4, Box 4595 Gig Harbor, WA 98335	Washington coastal and Puget Sound
Mokelumne Rearing Facility P.O. Box 158 Clements, CA 95227	California

Mossyrock Trout Hatchery P.O. Box 108 Mossyrock, WA 98564	Columbia Basin-Washington
Mullen Hatchery P.O. Box 448 Mullen, ID 83846	Columbia Basin-Idaho
Naches Trout Hatchery Rural Route 1 Naches, WA 98937	Columbia Basin-Washington
Nehalem Fish Hatchery Route 1, Box 292 Nehalem, OR 97131	Oregon coastal
Nelson Bridge Rearing Pond c/o Naches State Fish Hatchery Rural Route 1 Naches, WA 98937	Columbia Basin-Washington
Nemah Salmon Hatchery Star Route South Bend, WA 98586	Washington coastal and Puget Sound
Niagara Springs Hatchery P.O. Box 128 Wendell, ID 83355	Columbia Basin-Idaho
Nile Springs c/o Washington Dept. of Fisheries Rm 115, Gen. Admin. Bldg. Olympia, WA 98504	Columbia Basin-Washington
Nimbus Hatchery 2001 Nimbus Road Rancho Cordova, CA 95670	California
Nooksack Salmon Hatchery Glacier Star Route Deming, WA 98244	Washington coastal and Puget Sound
Northwest Steelheaders' Rearing Ponds c/o N.W. Steelheaders Council 3634 Walker Road Tacoma, WA 98443	Washington coastal and Puget Sound
Oakridge Fish Hatchery 76389 Fish Hatchery Pt. Oakridge, OR 97463	Columbia Basin-Oregon
Oak Springs Fish Hatchery Route 1, Box 134 Maupin, OR 97037	Columbia Basin-Oregon
Olympic Rearing Channel 420 Laird Port Angeles, WA 98362	Washington coastal and Puget Sound
Oregon Aqua Foods 88700 Marcola Road Springfield, OR 97477	Oregon coastal
Oxbow Hatchery P.O. Box 85 Oxbow, OR 97840	Columbia Basin-Idaho
OxBow Fish Hatchery Star Route, Box 750 Cascade Locks, OR 97014	Columbia Basin-Oregon
Pacific Lumber Co. Rearing Ponds c/o Pacific Lumber Council Scotia, CA 95565	California
Pahsimeroi Hatchery P.O. Box 84 Ellis, ID 83235	Columbia Basin-I
Percival Cove Rearing Pond c/o Washington Dept. of Fisheries Rm 115, Gen. Admin. Bldg. Olympia, WA 98504	Washington coasta Puget Sound
Prairie Creek Hatchery Orick, CA 95555	California
Priest Rapids Salmon Rearing Facility P.O. Box 937 Mattawa, WA 99344	Columbia Basin-W
Puntledge Rearing Facility c/o Big Qualicum Hatchery RR # 3 Qualicum Beach, British Columbia	British Columbia
Puyallup Salmon Hatchery Route 1, Box 97 Orting, WA 98360	Washington coasta Puget Sound
Puyallup Trout Hatchery 1416 14th Street Puyallup, WA 98371	Washington coasta Puget Sound
Quilcene National Fish Hatchery Quilcene, WA 98376	Washington coasta Puget Sound
Quinault National Fish Hatchery P.O. Box 80 Neilton, WA 98556	Washington coasta Puget Sound
Rapid River Hatchery (Circle "C" Hatchery) Riggins, ID 83549	Columbia Basin-W
Ringold Salmon Rearing Pond Star Route Mesa, WA 99343	Columbia Basin-W
Ringold Trout Rearing Pond Star Route Mesa, WA 99343	Columbia Basin-W
Roaring River Fish Hatchery 42255 Fish Hatchery Drive Scio, OR 97374	Columbia Basin-O
Robertson Creek Rearing Facility c/o Environment Canada Fisheries and Marine Service 1090 Pender St. Vancouver, British Columbia V6E 2P1	British Columbia
Rock Creek Fish Hatchery Toketee Route, Box 12 Idleyld Park, OR 97447	Oregon coastal
Rock Reach Salmon Rearing Facility 601 N. Jenifer Lane E. Wenatchee, WA 98801	Columbia Basin-W
Rosewall Rearing Facility c/o Pacific Biological Station P.O. Box 100 Nanaimo, British Columbia	British Columbia

tte Fish Hatchery O. Box 513 adras, OR 97741	Columbia Basin-Oregon
aring Pond Oregon Dept. of Fish and Wildlife O. Box 3503 OR 97208 Mr. Jefferies	Columbia Basin-Oregon
t Creek Rearing Pond (Closed) Washington Dept. of Game pitol Way WA 98504	Washington coastal and Puget Sound
mish Salmon Hatchery 555 vay 99 rlington, WA 98233	Washington coastal and Puget Sound
Hatchery gle, 83860	Columbia Basin-Washington
er Fish Hatchery . Fish Hatchery Road R 97055	Columbia Basin-Oregon
ward Park Hatchery rk A 98118	Washington coastal and Puget Sound
elton Trout Hatchery ox 251 A 98584	Washington coastal and Puget Sound
etz Fish Hatchery shville Route, Box 125 OR 97326	Oregon coastal
mpson Salmon Hatchery ute 1, Box 140 93541	Washington coastal and Puget Sound
mon Hatchery scade Route arblemount, WA 98267	Washington coastal and Puget Sound
Trout Hatchery ute 2, Box 464 ashougal, WA 98611	Columbia Basin-Washington
Rearing Ponds ox 395½ ltan, WA 98294	Washington coastal and Puget Sound
Salmon Hatchery ox 423 tan, A 98294	Washington coastal and Puget Sound
leduck Salmon Hatchery A 98305	Washington coastal and Puget Sound
uth Santiam Fish Hatchery iver Road e, OR 97386	Columbia Basin-Oregon
uth Sound Net Pens Washington Dept. of Fisheries en. Admin. Bldg. WA 98504	Washington coastal and Puget Sound
South Tacoma Trout Hatchery 7723 Phillips County Road, S.W. Tacoma, WA 98498	Washington coastal and Puget Sound
Speelyai Salmon Hatchery 11001 Lewis River Road Ariel, WA 98603	Columbia Basin—Washington
Spring Creek National Fish Hatchery Underwood, WA 98651	Columbia Basin—Washington
Squaxin Island Mariculture 33324 Pacific Highway Auburn, WA 98002	Washington coastal and Puget Sound
Starrigavan Net Pens P.O. Box 499 Sitka, AK 99835	Alaska
Stayton Rearing Pond c/o Aumsville Rearing Pond 8743 Bishop Road S.E. Aumsville, OR 97325	Columbia Basin-Oregon
Steilacoom Net Pens (Closed) c/o Washington Dept. of Fisheries Rm 115, Gen. Admin. Bldg. Olympia, WA 98504	Washington coastal and Puget Sound
Swofford Rearing Pond 1182 Spencer Road Winlock, WA 98596	Columbia Basin-Washington
Talmadge Rearing Pond c/o Mendocino County Offices Ukiah, CA 95482	California
Tokul Creek Trout Hatchery Route 1 Fall City, WA 98024	Washington coastal and Puget Sound
Toutle River Salmon Hatchery 1500 Cook Road Toutle, WA 98649	Columbia Basin-Washington
Trask River Fish Hatchery 15020 Chance Road Tillamook, OR 97141	Oregon coastal
Trinity River Hatchery P.O. Box 162 Lewiston, CA 96052	California
Tucannon Trout Hatchery Route 1, Box 32 Pomeroy, WA 99347	Columbia Basin-Washington
Tulalip Rearing Facility c/o Mr. Wayne Williams 3901 Totem Beach Road Marysville, WA 98270	Washington coastal and Puget Sound
Vancouver Trout Hatchery 12208 Evergreen Highway S.E. Vancouver, WA 98660	Columbia Basin-Washington
Wahkeena Rearing Pond c/o OxBow State Salmon Hatchery Star Route, Box 750 Cascade Locks, OR 97014	Columbia Basin-Oregon

Wallowa Fish Hatchery Route 1, Box 278 Enterprise, OR 97828	Columbia Basin-Oregon
Washburn Island Rearing Facility (Closed) c/o Washington Dept. of Game 600 N. Capitol Way Olympia, WA 98504	Columbia Basin-Washington
Washougal Salmon Hatchery Route 2, Box 443 Washougal, WA 98671	Columbia Basin-Washington
Wells Salmon Rearing Facility Box 3, Azwell Route Pateros, WA 98846	Columbia Basin-Washington
Wells Trout Hatchery Box 2, Azwell Route Pateros, WA 98846	Columbia Basin—Washington
Westport Boat Basin Rearing Facility c/o Washington Dept. of Fisheries Rm 115, Gen. Admin. Bldg. Olympia, WA 98504	Washington coastal and Puget Sound
Whidby Island Rearing Facility c/o Whidby Salmon Association P.O. Box 175 Clinton, WA 98236	Washington coastal and Puget Sound
Whistler's Bend Rearing Pond (Closed) c/o Oregon Dept. of Fish and Wildlife P.O. Box 3503 Portland, OR 97208 ATTEN: Mr. Jefferies	Oregon coastal
Whitehorse Rearing Pond Route 3, Box 229 Arlington, WA 98223	Washington coastal Puget Sound
Willapa Salmon Hatchery Route 1, Box 192 Raymond, WA 98577	Washington coasta Puget Sound
Willard National Fish Hatchery Star Route Cook, WA 98605	Columbia Basin-W
Winthrop National Fish Hatchery P.O. Box 218 Winthrop, WA 98862	Columbia Basin-W
Wizard Falls Fish Hatchery Camp Sherman, OR 97730	Columbia Basin-O
Yakima Trout Hatchery 2306 S. 16th Avenue Yakima, WA 98902	Columbia Basin-W

Appendix Table 2.—Agencies operating fish rearing facilities on the Pacific coast.

Agency	Address	Contact	Phone
Alaska Department of Fish and Game	F.R.E.D. 333 Raspberry Road Anchorage, AK 99502	Nikki Newcome	907-344-0541
California Department of Fish and Game	1001 Jedsmith Drive Sacramento, CA 95819	Patrick O'Brien	916-445-0111
Environment Canada-Fisheries and Marine Service	1090 West Pender St. Vancouver 1, B.C. V6E 2Pl	Ted Perry	604-666-6966
Humboldt County, California	C/o Prairie Creek Hatchery Orick, CA 95555	Steven Sanders	707-488-2253
Idaho Department of Fish and Game	600 South Walnut P.O. Box 25 Boise, ID 83707	Walt Bethke	208-964-3791
National Marine Fisheries Service (Alaska)	Auke Bay Research Station Box 155 Auke Bay, AK 99821	William Heard	907-789-7231
Oregon Department of Fish and Wildlife	P.O. Box 3503 Portland, OR 97208	Ernie Jefferies	503-229-5675
U.S. Fish and Wildlife Service	Suite 1692 Lloyd 500 Building 500 N.E. Multnomah St. Portland, OR 97232	Paul Handy	503-231-6216
Washington Department of Fisheries	Room 115, General Admin. Bldg. Olympia, WA 98501	Harry Senn	206-753-1872
Washington Department of Game	600 N. Capitol Way Olympia, WA 98504	James Gearhart	206-753-5713

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Movements of Pelagic Dolphins (*Stenella* Spp.) in the Eastern Tropical Pacific as Indicated by Results of Tagging, With Summary of Tagging Operations, 1969-76

W. F. Perrin, W. E. Evans, and
D. B. Holts

September 1979

U.S. DEPARTMENT OF COMMERCE
Juanita M. Kreps, Secretary
National Oceanic and Atmospheric Administration
Richard A. Frank, Administrator
National Marine Fisheries Service
Terry L. Leitzell, Assistant Administrator for Fisheries

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ovements of Pelagic Dolphins (*Stenella* Spp.) in the Eastern Tropical Pacific as Indicated by Results of gging, With Summary of Tagging Operations, 1969-76

W. F. PERRIN[1], W. E. EVANS[2], and D. B. HOLTS[1]

ABSTRACT

Through 1976, 3,712 small cetaceans were tagged in the course of research cruises operating out of the Southwest Fisheries Center. These included 2,996 spotted dolphins, *Stenella attenuata;* 324 spinner dolphins, *S. longirostis;* 193 common dolphins, *Delphinus delphis;* and 113 bottlenose dolphins, *Tursiops truncatus.* Others tagged in small numbers included Pacific whitesided dolphins, *Lagenorhynchus obliquidens;* striped dolphins, *Stenella coeruleoalba;* and a short-finned pilot whale, *Globicephala macrorhynchus.* Several types of tags were used. Tags have been recovered from 97 spotted dolphins and 7 spinner dolphins. Time at liberty ranged from less than 2 h to more than 4 yr. Net distance traveled ranged from 7 to 582 n.mi. Average short-term movement in the spotted dolphin is 30-50 n.mi./day; range is 200-300 n.mi. in diameter, and seasonal onshore-offshore migrations may exist.

INTRODUCTION

lations of pelagic dolphins are important to the
rse seine fishery for yellowfin tuna in the eastern
opical Pacific and are affected by the fishery.[3] Ade-
ssessment of the impacts of the fishery on the dol-
pulations requires knowledge of such aspects of
e history as home range and seasonal migration. For
is reason, we began a program of tagging dolphins in
he tagging program was specifically designed to
e movements, but the tagging itself was largely
pportunistic. In addition, research projects with other
es but involving tagging have also yielded infor-
on movements. The main purpose of this report is
summarize and to report the results of analyses of data
movements of spotted dolphins, *Stenella attenuata,*
nner dolphins, *S. longirostris,* yielded by tag
through 1976. A secondary purpose is to summa-
ze and document all dolphin tagging operations carried
t in conjunction with dolphin/tuna research at the
est Fisheries Center, La Jolla, Calif., from 1969
1976. This is necessary because of the possi-
lity that tagged dolphins released by us may be re-
vered by other investigators not familiar with our pro-
e suspended field work in our tagging program in
nding development of better tags and design of a
an for large-scale tagging aimed at estimating popula-
s. The results of the expanded program will be
ect of future reports.

Many small marine odontocetes are thought to undergo migrations of varying scale in time and distance. Most published conclusions about movements have been based on sightings or strandings and have to do with season of the year or sea surface temperature. Fraser (1934) noted a possible intrusion of elements of the warm-temperate Atlantic cetacean fauna (including *Delphinus delphis*) into the North Sea during a year of anomalous sea-surface warming. Sightings and correlated oceanographic data suggest that the distributions of dolphins (*Lissodelphis peroni, Lagenorhynchus cruciger, Lagenorhynchus obscurus,* and *Delphinus delphis*) off the east coast of New Zealand are "closely associated with certain temperature ranges and consequently with specific water masses and convergence regions," causing different animals to be seen in summer than in winter (Gaskin 1968). Similarly, Kasuya (1971) found, on the basis of aerial sightings, that warm-water delphinids, including *Stenella attenuata,* in Japanese waters migrate north in the summer season as far as Hokkaido; whereas cold-water forms, such as *Phocoenoides dalli* and *Lissodelphis borealis,* migrate south in the winter. The northern extent of the distribution of the warm-water forms may vary seasonally as much as 13° of latitude (780 n. mi.) (Miyazaki et al. 1974). Evans (1975) demonstrated the existence of similar seasonal migrations by the common dolphin, *D. delphis,* off the coasts of southern California and Baja California. Several other similar studies have been carried out, and this review is not exhaustive.

Very little information has been available on home range of pelagic dolphins. As Norris (1967) noted, some dolphins seem quite sedentary. He found that herds of spinner dolphins, *Stenella longirostris,* are consistently found off limited stretches of coast; five such home ranges have been tentatively recognized off Oahu, Hawaii. On the other hand, some other dolphins are very mobile. Herds of common dolphins off southern California and Baja California may move as far as 120 km in a 24-h period, following underwater escarpments (Evans 1971, 1974).

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[1] Southwest Fisheries Center, National Marine Fisheries Service,
a Jolla, CA 92038.
-Sea World Research Institute, Sea World, San Diego, CA
109.

[3] Report of the Workshop on Stock Assessment of Porpoises Involved in
Eastern Pacific Yellowfin Tuna Fishery. Unpubl. Manuscr., 109
C Admin. Rep. No. LJ-76-29, Nat. Mar. Fish. Serv., La Jolla,

Preliminary results of our tagging program through early 1974 have been previously published (Perrin 1975). Time at liberty for tagged spotted dolphins ranged from 1.7 h to 502 days and minimum distance traveled from 13 to 532 km.[4] The tentative conclusion was that these data indicate a great deal of east-west and north-south movement within the eastern portion of the range of the offshore race of *S. attenuata.* Tag returns for *S. lon*
showed less net movement.

MATERIALS AND METHODS

During the course of research on the dolph
problem, 3,712 small cetaceans were tagged (T
including 2,996 spotted dolphins (Fig. 1) and 324
dolphins (Fig. 2). One of us (Evans) carried out ot
phin-tagging operations during the period 1969-
these did not involve *Stenella* spp. and will be de
in another report. Several types of tags and tag
were used:

1. *Spaghetti tag with plastic dart.* This tag
scribed and figured by Nishiwaki et al. (196

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[4] A maximum value for minimum distance traveled of 2,415 km was given in Perrin (1975). Subsequently, additional information has been acquired concerning the recapture of that tag, and the data are now considered to be unreliable and are not included in the analysis below.

Table 1.—Dolphins and small whales tagged, 1969-76. Radiotags included.

Year	*Stenella attenuata*	*Stenella longirostris*	*Delphinus delphis*	*Tursiops truncatus*	Other	Unidentified	Total
1969	207	11	0	0	0	0	218
1970	618	94	10	0	0	[1]46	768
1971	147	18	50	12	[2]1	[3]15	243
1972	306	41	28	19	[2]7	0	401
1973	203	35	56	8	[4]2	1	305
1974	1,048	70	23	72	[2]7	1	1,221
1975	336	46	26	2	[5]4	[3]2	416
1976	131	9	0	0	0	0	140
Total	2,996	324	193	113	21	65	3,712

[1] Probability is high that these were either spotted dolphins, *Stenella attenuata,* or spinner dolphins, *S. longirostris.*

[2] Pacific white-sided dolphin, *Lagenorhynchus obliquidens.*

[3] Spotted or spinner dolphins.

[4] Striped dolphin, *Stenella coeruleoalba.*

[5] Two striped dolphins and two short-finned pilot whales, *Globicephala macrorhynchus.*

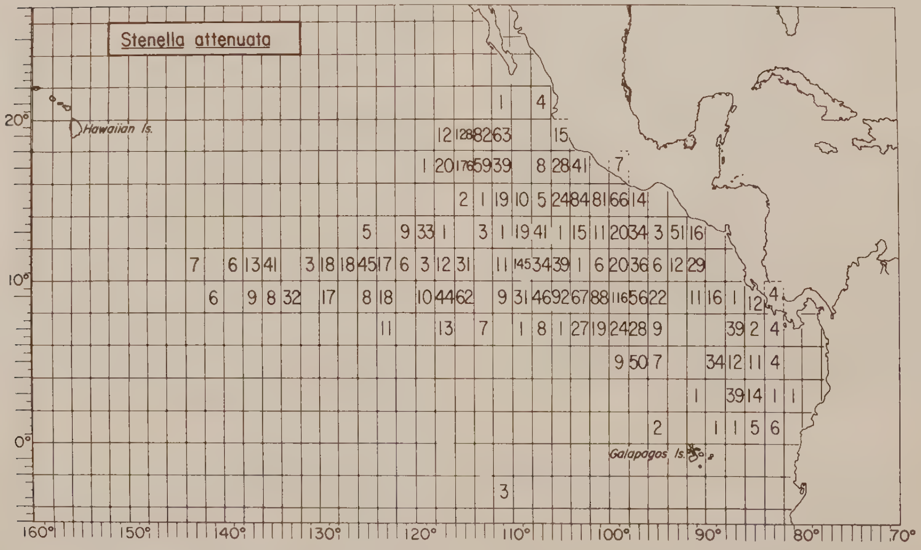

Stenella attenuata
Hawaiian Is.
Galapagos Is.
20°
10°
0°
160° 150° 140° 130° 120° 110° 100° 90° 80° 70°
1 4
12 128 82 63 15
1 20 176 59 39 8 28 41 7
2 1 19 10 5 24 84 81 66 14
5 9 33 1 3 1 19 41 1 15 11 20 34 3 51 16
7 6 13 41 3 18 18 45 17 6 3 12 31 11 145 34 39 1 6 20 36 6 12 29
6 9 8 32 17 8 18 10 44 62 9 31 46 92 67 88 116 56 22 11 16 1 12 4
11 13 7 1 8 1 27 19 24 28 9 39 2 4
9 50 7 34 12 11 4
1 39 14 1 1
2 1 1 5 6
3

Figure 1.—Number of releases of tagged spotted dolphins, *Stenella attenuata,* by 2-degree area, 1969-76. Releases given in Table 1 for which precise localities are not available are not included.

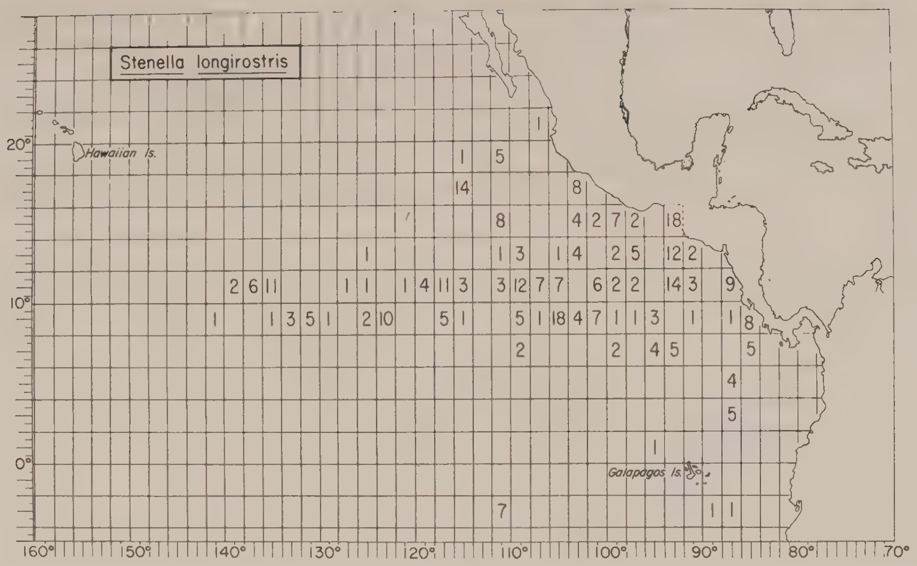


Figure 2.—Number of releases of tagged spinner dolphins, *Stenella longirostris*, by 2-degree area, 1969-76. Two dolphins given in Table 1 for which precise localities are not available are not included.

s released in 1969 and 1970 were yellow and bore one of two legends (in addition to serial number):

RETURN TUNA COMM SAN DIEGO or
REWARD BU COMM FISHERIES SAN DIEGO.

2. *Spaghetti tag with steel dart.* This type of tag was eloped for use on large pelagic fishes (Mather 1 3) and was first used on cetaceans by Sergeant and Brodie (1969). It has been modified from its original ign by addition of a clear plastic sleeve to protect legend (Evans et al.1972). It is manufactured by Floy Tag and Manufacturing, Inc., Seattle, Wash. Four versions of the tag were used in the operations cribed here:
   a. 15-cm long, orange, with legend:
      REWARD U.S. BUR COMM FISH LA JOLLA, CALIF(CF)
   12-cm long, yellow, with legend:
      REWARD NATL MARINE FISH SERVICE LA JOLLA, CAL
   2-cm long, yellow, with legend:
      NUC-502 SAN DIEGO, CAL. 92132 REWARD
   d. 30-cm long, orange, with legend:
      NATIONAL MARINE FISHERIES SERVICE LA JOLLA, CA U.S.A. REWARD.

Spaghetti tag with steel dart/braided. These tags e designed at sea for use in underwater observas of tagged dolphins during the research cruise of the *Elizabeth C. J.* in 1976 (see following section on Chronological Account of Tagging Operations, 1969- Three-strand braids of spaghetti tubing of various rs were linked together in unique color/length combinations and fastened to steel-dart tags from whic all but 1 in of tubing (bearing the serial number) ha been removed. Six-inch lengths of ½-in wide flexibl bright orange plastic streamers were added to the enc of some of the tags to further increase visibility.

4. *Plastic deer ear tag.* This tag ("jumbo rototag") wa described and figured by Norris and Pryor (1970). Ta and applicators are manufactured by Dalton, Henley United Kingdom.
   a. Tags released in 1971 were yellow and bore the leg end:
      DEVUELVA OF. DE PESCA PREMIO. 15 PESOS BU COMM FISH SAN DIEGO CO CABEZA
   b. Tags released in 1972 were yellow, with the leg end:
      $15 DOLLAR REWARD FOR RETURN WIT HEAD BU COM FISH SAN DIEGO
   c. Tags released in 1973 were white and bore no leg end other than the serial number.
5. *Radiotag.* Martin et al. (1971) and Evans (197 1974) described and figured the radiotags used.

CHRONOLOGICAL ACCOUNT OF TAGGING OPERATIONS, 1969-76

1. In 1969 and 1970, the Inter-American Tropical Tun Commission (IATTC) conducted tuna-tagging opera tions on three cruises on the chartered tuna seiner the *Connie Jean* and the *Anne M.* At NMFS' re quest, tuna tags (spaghetti tag with plastic dart—se discussion of tag types above) were also placed in do

phins captured with tuna (see Bayliff 1973 for description of tagging operations). Nine hundred and forty-nine dolphins were thusly tagged (Table 2).

2. In 1970, a crewman on the seiner *Conquest* volunteered to tag dolphins during fishing operations. He tagged 37 dolphins (probably spotted and spinner dolphins) with plastic-dart spaghetti tags.

3. Beginning in 1971, scientific observers from N each year have accompanied some tuna seiners "porpoise-fishing" grounds. Through 1975, observers tagged dolphins on an opportunity The observers tagged 105 dolphins on 3 crui 1971, 316 on 9 cruises in 1972, 204 on 16 crui 1973, 1,221 on 25 cruises in 1974, and 416 on 22 c in 1975 (Table 3). Two short-finned pilot w

Table 2.—Tags released from commercial seiners, 1969-76. Releases by NUMFS observers aboard nonchartered seiners are detailed in Table 3. Tag type PD = plastic-dart spaghetti tag, MD = metal-dart spaghetti tag (see Table 3), DE = deer ear tag, and RX = radio-transmitter tag. Letters a, b, and c refer to tag type subcategories defined in text.

			Tagged							
Vessel	Cruise number	Cruise period	Spotted dolphin	Spinner dolphin	Common dolphin	Bottlenosed dolphin	Other	Unidentified	Total	Tag type
Connie Jean	1055	Oct-Nov 69	207	11	0	0	0	0	218	PD (a)
Anne M	1057	Jun-Aug 70	≥278	≥46	10	—	—	9	343	PD (61a, 278b)
Anne M	1058	Sep-Nov 70	340	48	0	0	0	0	388	PD (b)
Conquest	—	Mar-Apr 70	—	—	—	—	—	37	37	PD (b)
Queen Mary	13	Nov-Dec 71	≥105	—	0	0	0	[1]15	120	MD (107b, 24c)
			15	0	0	0	0	0	15	DE (a)
			3	0	0	0	0	0	3	RX
Independence	26	Sep-Oct 72	1	4	18	0	[2]1	0	24	MD (a)
			61	0	0	0	0	0	61	DE (b)
Trinidad	52	Oct-Nov 73	12	1	7	0	0	0	20	MD (a)
John F. Kennedy	53	Nov-Dec 73	59	0	0	0	0	0	59	MD (a)
			22	0	0	0	0	0	22	DE (c)[3]
Elizabeth C J	208	Oct-Dec 76	124	8	0	0	0	0	132	MD[4]
			7	1	0	0	0	0	8	RX
Total			1,234	119	35	0	1	61	1,450	

[1] Spotted or spinner.

[2] Pacific white-sided dolphin, *Lagenorhynchus obliquidens*.

[3] With 2-in disc.

[4] With braided tubing.

Table 3.—Tag releases (steel-dart spaghetti tags) by NMFS observers aboard commercial tuna seiners, 1971-75. Tag types defined in text.

		Tagged								
Cruise number	Year	Spotted dolphin	Spinner dolphin	Common dolphin	Bottlenose dolphin	Other	Unidentified	Totals		Tag type
6	1971	0	0	23	0	[1]1	0	24		(a)
8		8	18	17	11	0	0	54		(a)
9		16	0	10	1	0	0	27	105	(10c, 95a)
14	1972	18	0	0	0	0	0	18		(a)
15		43	0	2	0	0	0	45		(a)
16		22	21	0	0	0	0	43		(a)
17		6	0	2	9	[1]6	0	23		(a)
20		16	0	0	0	0	0	16		(a)
21		54	1	0	1	0	0	56		(a)
22		32	13	0	0	0	0	45		(a)
23		15	0	0	0	0	0	15		(a)
24		38	2	6	9	0	0	55	316	(a)
29	1973	2	4	7	0	0	0	13		(a)
30		12	5	0	0	0	1	18		(a)
31		1	0	0	0	0	0	1		(a)
32		1	0	0	0	0	0	1		(a)
33		1	0	0	0	0	0	1		(a)
34		9	0	0	0	0	0	9		(a)
38		4	1	0	0	0	0	5		(a)
39		1	0	0	0	0	0	1		(a)
40		1	0	0	0	0	0	1		(a)
41		12	10	6	0	0	0	28		(a)
43		5	1	4	0	0	0	10		(a)
44		11	1	4	0	[2]2	0	18		(a)
45		23	0	8	0	0	0	31		(a)
47		7	0	4	0	0	0	11		(a)
48		9	12	16	8	0	0	45		(a)

Table 3.—Continued.

Cruise number	Year	Tagged						Totals		Tag type
		Spotted dolphin	Spinner dolphin	Common dolphin	Bottlenose dolphin	Other	Unidentified			
49		11	0	0	0	0	0	11	204	(a)
54	1974	0	3	0	0	0	0	3		(a)
55		3	0	0	0	0	0	3		(b)
57		16	3	0	0	0	0	19		(a)
58		47	3	0	9	0	0	59		(a)
59		24	8	2	4	0	0	38		(a)
61		51	8	4	17	[1]3	0	83		(b)
65		17	0	4	0	0	0	21		(a)
66		29	0	0	0	0	0	29		(a)
67		0	1	0	0	0	0	1		(a)
68		20	1	7	0	0	0	28		(b)
71		2	5	0	0	0	0	7		(a)
72		1	0	0	0	0	0	1		(b)
73		3	2	0	0	0	0	5		(a)
74		34	1	0	0	0	1	36		(b)
75		2	0	0	0	0	0	2		(a)
76		1	1	0	0	0	0	2		(a)
78		8	0	0	0	0	0	8		(b)
80		10	0	0	0	0	0	10		(a)
81		2	0	0	8	0	0	10		(b)
82		34	0	0	0	0	0	34		(a)
87		91	5	6	32	[1]4	0	138		(b)
90		5	7	0	0	0	0	12		(a)
91		623	14	0	2	0	0	639		(a)
94		5	2	0	0	0	0	7		(a)
96		20	6	0	0	0	0	26	1,221	(a)
99	1975	1	0	0	0	0	0	1		(a)
100		16	0	0	1	0	0	17		(d)
102		43	2	0	0	[2]1	0	46		(d)
104		42	4	0	0	0	[3]2	48		(d)
105		18	2	0	0	0	0	20		(d)
106		45	3	0	1	0	0	49		(d)
110		3	0	0	0	[2]1	0	4		(d)
112		42	8	0	0	0	0	50		(d)
113		27	10	0	0	0	0	37		(d)
114		1	0	0	0	0	0	1		(d)
115		6	1	0	0	0	0	7		(b)
116		2	1	0	0	0	0	3		(d)
117		1	0	0	0	0	0	1		(d)
118		0	2	0	0	0	0	2		(d)
119		15	5	0	0	0	0	20		(d)
120		1	0	0	0	0	0	1		(d)
121		43	0	0	0	0	0	43		(d)
123		8	1	2	0	[4]2	0	13		(d)
124		1	0	0	0	0	0	1		(d)
125		5	0	0	0	0	0	5		(d)
129		16	7	24	0	0	0	47	416	(d)
	Total	1,762	205	158	113	20	4	2,262		

[1] Pacific white-sided dolphin, *Lagenorhynchus obliquidens*.

[2] Striped dolphin, *Stenella coeruleoalba*.

[3] Spotted dolphin or spinner dolphin.

[4] Short-finned pilot whale, *Globicephala macrorhynchus*.

lobicephala macrorhynchus, were also tagged in 1975. Before application, the tag heads were sprayed opazone, a topical antibiotic. The tags were applied in several different ways:

a. h the bow (when animals rode the bow wave), a quick-release head (Beckett 1968) mounted on a long wooden pole or with a crossbow (as described by Kasuya and Oguro 1972, but using a ber stop on the crossbow bolt rather than a s stop);
b. from a skiff at the corkine of the seine during the dolphin-rescue maneuver called "backing-down" (see Perrin 1969 for details of fishing operation), using short (40 cm) wooden wands, with permanently mounted tag pins, as applicators; and
c. on the work-deck, when live dolphins were extricated from the net or the catch and then thrown overboard, using short applicators.

4. In late 1971, NMFS chartered the tuna seiner *Queen Mary* for a dolphin/tuna research cruise on the fishing

grounds. Three tagging operations were carried out on the cruise.

a. Radiotags were attached to spotted dolphins, to monitor herd movements, herd integrity, and recruitment of associated yellowfin tuna to the herd. The technique has been described by Evans (1971, 1974). Five dolphins were radiotagged and followed.
b. Fifteen spotted dolphins were measured, sexed, and injected with lead acetate and tagged with plastic deer ear tags placed in the dorsal fin. The animals were pulled into a small skiff for examination and tagging. Technique of application was described by Norris and Pryor (1970). The purpose of the injection of lead acetate was to lay down a time check in the hard tissues, so that growth rates in teeth and bone could be calibrated through examination of recaptured animals. The technique was developed by Nishiwaki and Yagi (1953). The tagged animals were also injected with an antibiotic to combat sepsis. Results of this experiment will be analyzed when tags are returned (none returned with sufficient data to date).
c. One hundred and twenty dolphins were also tagged with steel-dart spaghetti tags.

5. In late 1972, NMFS chartered the seiner *Independence* for a dolphin/tuna cruise. Sixty-one spotted dolphins were injected with lead acetate and tagged with plastic deer ear tags. Tagging was accomplished through use of an aluminum chute supported by two skiffs at the corkline of the seine (Fig. 3). In addition, 24 dolphins were tagged with steel-dart spaghetti tags.

6. Also in 1973, the seiner *Trinidad* was chartered by NMFS for technological research on dolphin rescue methods and equipment. During the cruise, 20 dolphins were tagged with steel-dart spaghetti tags.

7. In late 1973, NMFS chartered the seiner *John F. Kennedy*. The main purpose of the cruise was to conduct research on dolphin-rescue methods, but some tagging was also carried out. Twenty-two spotted dolphins in a single herd were tagged with white deer ear tags, inserted in the dorsal fin. A 2-in diameter thin red plastic disc was placed on the tag post on each side of the fin to increase visibility of the tag in the water. The objective was to tag dolphins in several herds, using a different color for each herd, and then to study herd structure and integrity through observation of tagged animals in the seine in subsequent hauls in the same area. Rough weather, however, prevented further use of the tagging chute (described above) and completion of the scheduled tagging. In addition to the 22 dolphins tagged with ear tags, 59 spotted dolphins were tagged with steel-dart spaghetti tags.

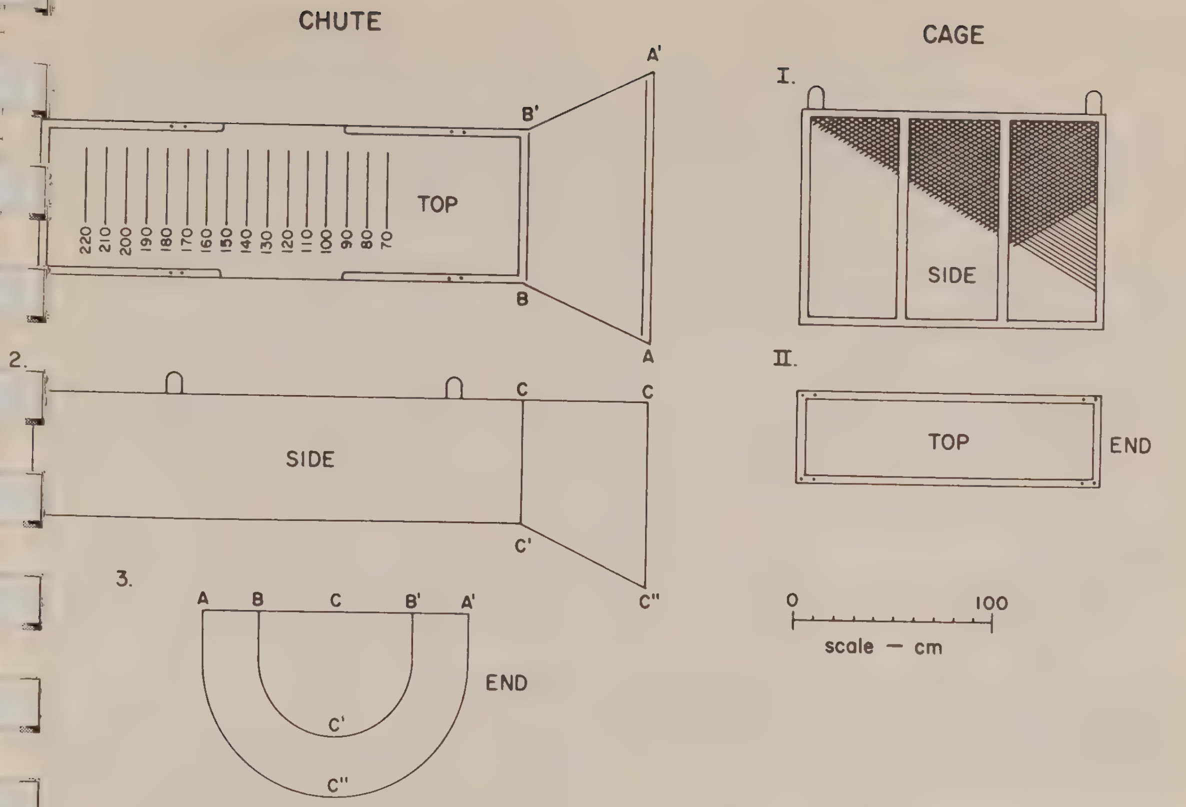
8. In late 1976, NMFS chartered the seiner *Elizabe* *J.* for a combined dolphin/tuna behavioral res and gear research cruise sponsored by several go mental and private organizations. Two types o were used to mark dolphin schools so that they be followed and recaptured and the tagged dol observed in the net. Radiotags were placed on spotted dolphins and one spinner dolphin. The tags failed after only a few hours, but two were s quently recovered (the recoveries are treated like other tag returns; the radio-transmitted dat be presented elsewhere). In addition, 124 spotte phins and 8 spinner dolphins were tagged with dart spaghetti tags modified for greater under visibility (see 3. *Spaghetti tag with steel dart/br* above).

ACCOUNT OF RADIOTRACKING EXPERIMENT

Transmitters were placed on one adult male (a A) and two adult females (animals B and C) captu a tuna seine on 21 November 1971. The object experiment was to track the school and set the what was assumed to be the same herd five times, a intervals and at about 1000. The initial set was afternoon, and the tagged animals were not releas til almost sunset. The chronology of events (Fig. 4 be summarized as follows:

After the release of the tagged animals it beca creasingly obvious that the behavior of the mal quite different from that of the females. At first a mals appeared to stay on the same relative he After sunset the females began to move away fro male and the decision was made to stay with the After 6 h of tracking the females were separated fro male by an estimated 12 n.mi. and their trans signals were extremely weak. It was assumed the mitter on at least one of the two animals (B and failed.

The vessel followed the male (A) until 1040 on vember when the first recapture set was made (Net distance traveled between initial release and capture was 59 n.mi., in about 16 h. One of the f (C) rejoined the male (A) at 0800 but separated fro again at 0930 prior to the net set. An additiona range transmitter was placed on another male (D) set 2. Also, a long-life, short-range transmitt placed on another female (E). After release, A stayed together and were rejoined by one of the f from the first set (C). Female B was not seen ag lowing her separation from A and C after initial rel set 2. A, D, E, and C were followed until 1036 (set 3 November. Net distance traveled in 24 h was 2 During this period, the males (A and D) were se by some distance (3 n.mi.) from the school contain females (C and E). The set (3) was made on the of the school containing the males A and D. They capture by passing between the boat and the net s


CHUTE
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END
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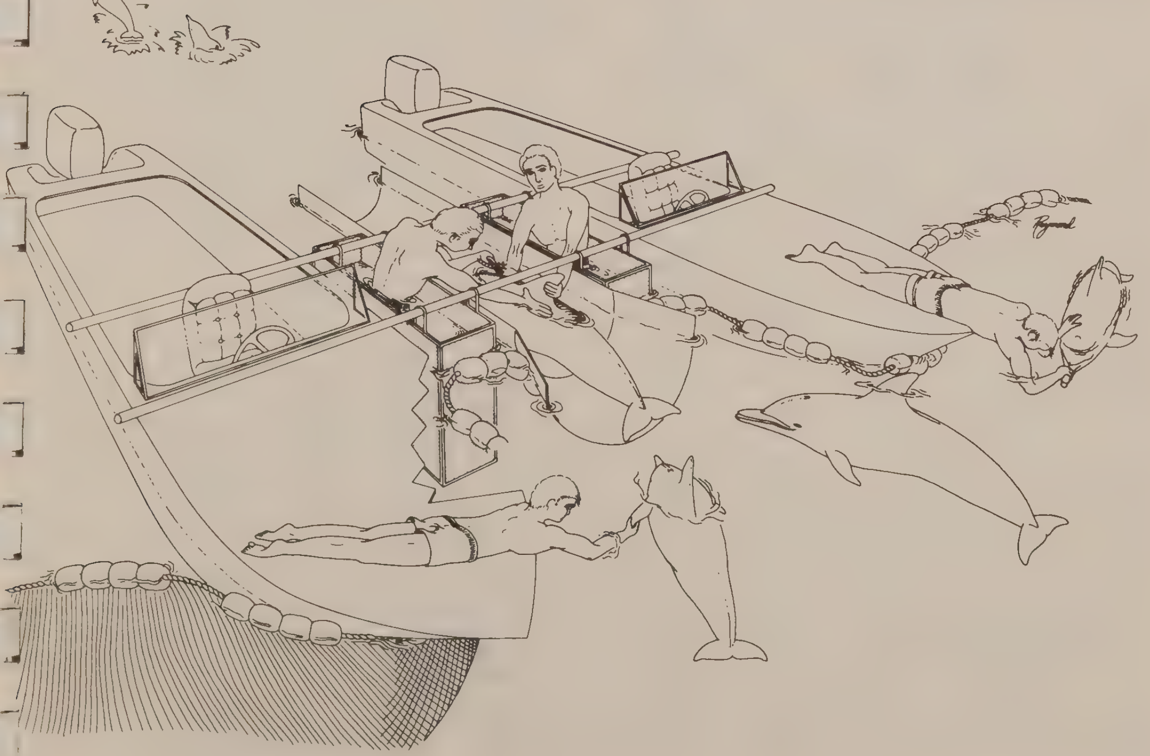
Figure 3.—Chute system used for tagging dolphins in the tuna seine.



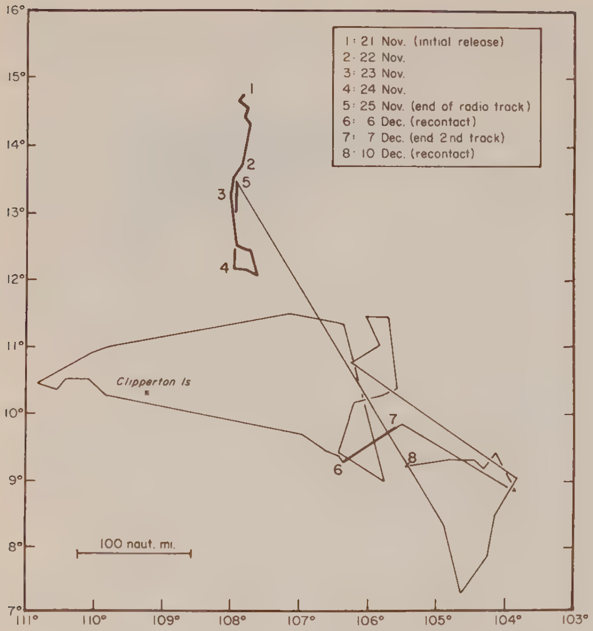


Figure 4.—Cruise track of chartered purse seiner *Queen Mary* while tracking movement of school of radiotagged spotted dolphins, *Stenella attenuata*, in November-December 1971. Heavy lines represent portions of the cruise track when radio contact was maintained with the school. The lines represent movements of the vessel, not necessarily the exact route of the radio-tagged animals.

fore completion of the net circle. After the set, A and D were followed until 2200 when they separated. Male D was followed, with a faint signal in the background from A, until 1020 on 24 November (set 5). Net distance traveled in this 24-h period was 69 n.mi., but actual distance traveled was about 110 n.mi. (Fig. 4). At this time, A and D had reconverged, but the set was made on the portion of the school containing D. Animal D again eluded capture in the seine. A and D rejoined after the set and were followed until 0700 on 25 November when the track was terminated because of an approaching storm. Net distance traveled during this 22-h period was approximately 75 n.mi. The school had doubled back and was heading north on almost exactly the same path it had followed south 3 days before. Total net distance traveled during the 110 h of the 5-day radiotrack was only about 75 n.mi., about one-fourth of the actual distance traveled. Maximum distance between any two points on the track was about 160 n.mi.

On 6 December, 11 days and approximately 285 n.mi. distance from termination of the first track, signals from both of the males (A and D) were picked up at 1255 and followed until 0750 on 7 December when strong signals were received from A in a school of <30 spotted dolphins. The school was chased to allow close approach and a good estimate of size, but no net set was made, and the school was not further followed. Net distance traveled during this 19-h second radiotrack was about 75 n.mi. Three days later, on 10 December, at 0925, signals were again received from A and D, and, this time, also from
the female C, which had not been heard from since
rating from the males on 23 November. The males
females were again segregated within the school.
school was not set on or followed after this recontact
the research cruise ended shortly thereafter. Net dist
traveled by the school between initial release and
contact (19 days) was 357 n.mi. (19 n.mi./day, s
southeast).

RESULTS AND DISCUSSION

Of 3,712 tags released from 1969 through 1976, 10
been returned as of 1 January 1977 (Tables 3, 4).
were recovered only from spotted dolphins (97) and
ner dolphins (7). Time at liberty ranged from 1 h a
min to 1,478 days for *S. attenuata* and from 15 h a
min to 776 days for *S. longirostris*. Minimum dis
traveled (distance between release and recovery
tions) ranged from 7 to 582 n.mi. for *S. attenuata* (F
and 12 to 275 n.mi. for *S. longirostris* (Fig. 6). Deta
returns are presented in Tables 4, 5. Returns are
cient for the spotted dolphin to allow some ana
based on these and on the results of radiotagging.

Short-Term Movements

Twenty-six tagged spotted dolphins were recap
within 2 days (48 h) after release (Fig. 7). Longer ter
coveries were not included in the analysis because
increasing potential for bias caused by the an
doubling back on themselves (see results of radiota
experiment above). A linear regression line fitted t
data has a slope indicating an average movement r
about 1.2 n.mi./h (about 30 n.mi./day).

The results of the radiotagging experiment inc
daily movement rates of similar scale (Fig. 4), yie
estimates of net daily travel rate ranging from 5
n.mi. and an average of 54 n.mi./day (Table 6), as
pared with the estimate of about 30 n.mi./day bas
short-term tag returns. The former can be assumed
less affected by the "doubling back" factor.

Long-Term Movements

A plot of minimum distance traveled on time at li
for all tag returns shows maximum movement of
600 n.mi. (Fig. 8). The data may have a periodic
ponent. Average minimum distance traveled is 100
for 10- to 50-day returns (n = 21) and 274 n.mi. for
200-day returns (n = 12) but only 93 n.mi. for 200- t
day returns (n = 15). A major question in interp
these results is that of recovery effort. Tags are
ered during the fishing operation. Was there
ficantly more fishing effort in areas <200 n.mi.
areas in which tags were released 200 to 400 days e
than in areas more than 200 n.mi. from areas of rel
In other words, could the data reflect periodic fishi
fort rather than periodic movement of dolphins? In
tempt to settle this question, we examined, for ea
the 50- to 200-day returns (12) and each of the 2

.—Tag return data for spotted dolphin, *Stenella attenuata*, 1969-76. Recovered radiotags included. Tag type codes defined in text.

Release				Recapture			Days at liberty (or h)	Minimum distance traveled (n.mi.)	Direction net movement		Tag type	Tag number
Date	Cruise number	Position lat. N	Position long. W	Date	Position lat. N	Position long. W			°T	bearing		
1 Nov 69	1055	14°17′	98°58′	1970	—	—	60	—	—	—	PD (a)	T3154
Nov 69	1055	13°49′	99°20′	25 Feb 70	15°39′	101°09′	114	152	316	NW	PD (a)	T3160
Nov 69	1055	15°03′	101°42′	3 Mar 70	15°10′	100°41′	119	59	83	E	PD (a)	T3193
17 Nov 69	1055	10°28′	107°40′	3 Apr 70	7°58′	98°10′	137	582	104	ESE	PD (a)	A1171
18 Nov 69	1055	10°58′	107°34′	19 Nov 69	10°41′	107°08′	(24 h)	31	124	SE	PD (a)	A1181
18 Nov 69	1055	11°09′	107°20′	5 Mar 70	13°20′	100°15′	107	435	72	ENE	PD (a)	A1199
Sep 70	—	9°46′	140°50′	3 Dec 70	9°32′	134°15′	83	390	92	E	MD (b)	P1019
Nov 71	13	12°11′	107°57′	11 Jan 72	11°37′	105°03′	48	174	101	E	MD (c)	01667
7 Dec 71	13	9°49′	105°29′	12 Jan 72	10°40′	106°31′	36	67	320	NW	MD (c)	00769
8 Dec 71	13	10°15′	104°32′	9 Dec 72	9°16′	104°26′	(15 h)	59	174	S	MD (a)	00013
Dec 71	13	9°17′	104°48′	10 Feb 72	9°16′	98°40′	63	363	90	E	MD (a)	00096
Dec 71	13	9°17′	104°48′	10 Feb 72	9°16′	98°40′	63	363	90	E	MD (a)	00099
11 Dec 71	26	9°21′	105°50′	12 Jan 72	10°40′	106°13′	32	82	344	NNW	DE (b)	116
11 Dec 71	26	9°21′	105°50′	8 Jan 72	8°50′	104°40′	28	76	144	ESE	DE (b)	118
13 Jan 72	14	7°10′	102°30′	1973	—	—	—	—	—	—	MD (a)	00609
Jan 72	17	10°30′	99°50′	10 Feb 72	9°50′	97°10′	20	162	104	ESE	MD (a)	00591
Jan 72	16	6°15′	98°58′	31 Jan 72	6°07′	99°36′	(21 h)	40	252	WSW	MD (a)	00434
24 Feb 72	16	14°54′	99°34′	4 Mar 72	14°40′	100°55′	9	80	260	W	MD (a)	00457
25 Feb 72	21	9°45′	98°35′	28 Mar 72	10°35′	100°55′	32	147	290	WNW	MD (a)	00475
Mar 72	22	9°28′	98°21′	11 Apr 72	13°16′	96°22′	15	256	27	NNE	MD (a)	00111
Aug 72	26	12°30′	109°23′	21 Feb 74	12°55′	99°41′	501	568	86	E	DE (b)	011
Oct 72	26	10°28′	104°03′	15 Nov 76	—	—	1478	—	—	—	DE —	039
27 Mar 73	45	9°53′	96°17′	—	—	—	—	—	—	—	MD (a)	01425
6 Feb 74	61	17°37′	112°41′	3 Aug 74	19°20′	113°25′	179	111	338	NNW	MD (b)	02959
Feb 74	61	17°24′	102°24′	9 Feb 74	17°29′	102°19′	(2 h)	7	44	NE	MD (b)	02986
Feb 74	59	11°05′	90°38′	29 Jan 75	12°45′	91°43′	345	119	328	NNW	MD (a)	01457
18 Feb 74	59	9°37′	91°26′	6 Mar 74	11°20′	91°23′	16	103	2	N	MD (a)	01461
18 Feb 74	59	9°37′	91°26′	6 Mar 74	11°40′	91°50′	16	125	349	N	MD (a)	01469
20 Feb 74	58	14°46′	102°09′	20 Feb 74	14°39′	102°11′	(2 h)	7	188	S	MD (a)	00837
Feb 74	66	14°15′	102°20′	27 Feb 74	14°38′	102°38′	(54 h)	32	328	NNW	MD (a)	00073
Apr 74	82	5°10′	89°10′	4 Mar 75	4°22′	87°02′	334	136	111	ENE	MD (a)	00059
19 Jun 74	91	18°16′	115°51′	7 Mar 75	16°32′	113°30′	260	170	127	SE	MD (b)	02101
20 Jun 74	91	18°00′	114°50′	30 Jun 74	18°09′	115°49′	10	57	279	W	MD (b)	02699
Jun 74	91	17°54′	114°02′	22 Jun 74	17°57′	113°38′	(14 h)	23	82	E	MD (b)	02085
Jun 74	91	17°20′	114°23′	30 Jun 74	18°09′	115°17′	9	71	314	NW	MD (b)	02691
21 Jun 74	91	17°20′	114°23′	1 Jul 74	18°19′	114°23′	10	39	356	N	MD (b)	02694
22 Jun 74	91	18°27′	113°19′	13 Dec 74	20°07′	112°15′	174	117	31	NNE	MD (b)	02032
22 Jun 74	91	18°27′	113°91′	20 Apr 75	17°23′	114°09′	302	80	217	SW	MD (b)	02037
Jun 74	91	18°20′	113°17′	1 Jul 74	18°19′	114°23′	9	63	269	W	MD (b)	02042
Jun 74	91	18°20′	113°17′	—	—	—	—	—	—	—	MD (b)	02047
22 Jun 74	91	17°57′	113°38′	25 Jun 74	17°10′	115°00′	3	91	239	WSW	MD (b)	02071
23 Jun 74	91	18°00′	113°00′	24 Jun 74	17°53′	113°06′	(14 h)	9	219	SW	MD (a)	00395
Jun 74	91	18°00′	113°00′	15 Apr 75	18°17′	113°36′	296	38	297	WNW	MD (a)	00398
Jun 74	91	18°00′	113°00′	8 Aug 74	18°12′	114°45′	46	101	277	W	MD (b)	02029
Jun 74	91	17°50′	116°00′	20 Apr 75	17°23′	114°09′	298	109	104	ESE	MD (a)	00376
28 Jun 74	91	17°45′	115°00′	3 May 75	18°12′	114°20′	315	47	55	NE	MD (a)	00667
28 Jun 74	91	17°45′	115°00′	30 Jun 74	18°09′	115°49′	(45 h)	52	297	WNW	MD (a)	01037
Jun 74	91	17°45′	115°00′	29 Jun 74	17°57′	115°22′	(18 h)	24	300	WNW	MD (a)	01039
Jun 74	91	18°07′	115°08′	5 Aug 74	19°08′	116°00′	37	70	330	NNW	MD (a)	01016
29 Jun 74	91	17°57′	115°22′	30 Jun 74	18°09′	115°49′	(25 h)	28	295	WNW	MD (a)	01056
30 Jun 74	91	18°09′	115°49′	5 Aug 74	18°05′	114°10′	36	94	92	E	MD (a)	01023
30 Jun 74	91	18°09′	115°49′	5 Aug 74	19°08′	116°00′	36	60	350	N	MD (a)	01028
Jul 74	91	18°19′	114°23′	2 Jul 74	18°35′	114°40′	(17 h)	23	315	NW	MD (a)	01043
Jul 74	91	18°19′	114°23′	2 Jul 74	18°35′	114°40′	(17 h)	23	315	NW	MD (a)	01050
1 Jul 74	91	18°19′	114°23′	2 Jul 74	18°35′	114°40′	(17 h)	23	315	NW	MD (a)	01093
1 Jul 74	91	18°19′	114°23′	2 Jul 74	18°35′	114°40′	(17 h)	23	315	NW	MD (a)	01094
Jul 74	91	17°58′	114°36′	4 Aug 74	19°00′	114°26′	34	63	9	N	MD (a)	01077
Jul 74	91	17°58′	114°36′	4 Aug 74	19°00′	114°26′	34	63	9	N	MD (a)	01084
1 Jul 74	91	17°58′	114°36′	7 Jul 74	16°50′	114°15′	6	71	164	SSE	MD (a)	01079
2 Jul 74	91	18°35′	114°40′	5 Jul 74	18°18′	114°12′	3	32	123	ESE	MD (a)	01069
2 Jul 74	91	18°12′	114°26′	4 Aug 74	19°00′	114°23′	33	48	3	N	MD (b)	02013
Jul 74	91	18°12′	114°23′	3 Aug 74	19°20′	113°25′	32	87	39	NE	MD (b)	02018
Jul 74	91	18°23′	114°46′	9 May 75	18°12′	114°20′	308	27	114	ESE	MD (b)	02060
5 Jul 74	91	18°18′	114°12′	20 Apr 75	17°23′	114°09′	289	55	117	S	MD (b)	02117
5 Jul 74	91	18°18′	114°12′	3 Aug 74	19°20′	113°25′	29	76	36	NE	MD (b)	02118
Jul 74	91	18°28′	111°00′	16 Nov 74	20°05′	109°39′	108	124	38	NE	MD (b)	02534
Aug 74	91	19°40′	110°12′	24 Mar 75	16°00′	109°40′	235	222	172	S	MD (b)	02745

Table 4.—Continued.

	Release				Recapture			Days at liberty (or h)	Minimum distance traveled (n.mi.)	Direction net movement		Tag type	
	Date	Cruise number	Position lat. N	Position long. W	Date	Position lat. N	Position long. W			°T	bearing		
68	3 Aug 74	91	19°20′	113°25′	20 Apr 75	17°23′	114°09′	259	124	200	SSW	MD	(b)
69	4 Aug 74	91	19°00′	114°26′	14 Apr 75	17°07′	113°33′	252	123	156	SSE	MD	(b)
70	4 Aug 74	91	19°00′	114°26′	20 Apr 75	17°23′	114°09′	258	98	171	S	MD	(b)
71	8 Aug 74	91	18°12′	114°45′	22 May 75	17°20′	114°55′	287	53	190	S	MD	(b)
72	9 Aug 74	91	18°40′	113°55′	10 Apr 75	17°10′	114°15′	244	92	192	SSW	MD	(b)
73	17 Aug 74	91	11°15′	109°05′	18 Aug 75	11°34′	108°16′	(19 h)	52	68	ENE	MD	(b)
74	17 Aug 74	91	10°54′	109°13′	18 Aug 75	11°34′	108°16′	(25 h)	71	52	NE	MD	(b)
75	17 Aug 74	91	10°54′	109°13′	17 Aug 75	11°15′	109°05′	(5 h)	22	20	NNE	MD	(b)
76	17 Aug 74	91	10°54′	109°13′	17 Aug 75	11°15′	109°05′	(5 h)	22	20	NNE	MD	(b)
77	17 Aug 74	91	10°54′	109°13′	17 Aug 75	11°15′	109°05′	(5 h)	22	20	NNE	MD	(b)
78	7 Jan 75	99	20°14′	110°32′	13 Jan 75	19°35′	110°20′	6	41	164	SSE	MD	(a)
79	21 Jan 75	100	13°35′	100°35′	30 Mar 75	12°59′	103°00′	68	146	256	WSW	MD	(d)
80	30 Jan 75	102	14°47′	99°09′	3 May 75	15°31′	109°00′	93	572	276	W	MD	(d)
81	31 Jan 75	112	13°08′	91°50′	1 Feb 75	13°12′	91°38′	(16 h)	12	71	ENE	MD	(d)
82	31 Jan 75	112	13°08′	91°50′	1 Feb 75	13°12′	91°38′	(16 h)	12	71	ENE	MD	(d)
83	31 Jan 75	112	13°08′	91°50′	18 Feb 75	12°23′	91°38′	18	47	165	SSE	MD	(d)
84	18 Feb 75	112	9°25′	95°15′	5 Aug 75	9°13′	99°18′	168	240	267	W	MD	(d)
85	19 Feb 75	113	9°20′	95°43′	21 Feb 75	9°08′	96°55′	2	72	261	W	MD	(d)
86	21 Feb 75	113	9°01′	97°57′	23 Feb 75	8°32′	98°28′	2	42	227	SW	MD	(d)
87	21 Feb 75	113	9°01′	97°57′	23 Feb 75	8°32′	98°28′	2	42	227	SW	MD	(d)
88	22 Feb 75	119	12°10′	92°10′	2 Mar 75	12°48′	92°37′	8	46	325	NW	MD	(d)
89	14 Apr 75	121	17°07′	113°33′	21 Apr 75	17°29′	114°11′	7	42	301	NNW	MD	(d)
90	14 Apr 75	121	17°07′	113°33′	21 Apr 75	17°29′	114°11′	14	54	152	WNW	MD	(d)
91	21 Apr 75	105	14°48′	109°15′	5 May 75	14°00′	108°49′	14	54	152	SSE	MD	(d)
92	21 Apr 75	105	14°48′	109°15′	5 May 75	14°00′	108°49′	14	54	152	SSE	MD	(d)
93	24 Oct 76	208	9°33′	104°46′	26 Oct 76	9°11′	105°01′	(15 h)	26	214	SW	MD[1]	—
94	25 Oct 76	208	9°33′	104°46′	26 Oct 76	9°11′	105°01′	(15 h)	26	214	SW	MD[1]	—
95	25 Oct 76	208	9°33′	104°46′	26 Oct 76	9°11′	105°01′	(15 h)	26	214	SW	MD[1]	—
96	25 Oct 76	208	9°33′	104°46′	26 Oct 76	9°11′	105°01′	(15 h)	26	214	SW	RX	—
97	25 Oct 76	208	9°33′	104°46′	26 Oct 76	9°11′	105°01′	(15 h)	26	214	SW	RX	—

[1] With braided tubing.

Table 5.—Tag return data for spinner dolphin, *Stenella longirostris*, 1969-76. Tag type codes defined in text.

	Release				Recapture			Days at liberty (or h)	Minimum distance traveled (n.mi.)	Direction of net movement		Tag type	
	Date	Cruise number	Position lat. N	Position long. W	Date	Position lat. N	Position long. W			°T	bearing		
1	18 Aug 70	26	10°47′	127°48′	17 Sep 71	11°17′	123°09′	395	275	83	E	PD	(a)
2	23 Nov 71	13	13°20′	108°00′	8 Jan 74	11°44′	105°32′	776	172	124	SE	MD	(a)
3	8 Dec 71	13	10°15′	104°32′	28 Feb 72	11°01′	101°15′	82	199	76	ENE	MD	(a)
4	8 Dec 71	13	10°15′	104°32′	28 Feb 72	11°01′	101°15′	82	199	76	ENE	MD	(a)
5	10 Jan 72	16	9°04′	105°01′	6 Feb 72	9°35′	108°10′	37	189	280	W	MD	(a)
6	31 Jan 75	112	13°08′	91°50′	1 Feb 75	13°12′	91°38′	(16 h)	12	71	ENE	MD	(d)
7	13 Apr 75	105	6°38′	93°21′	16 Apr 75	6°54′	94°43′	3	83	281	W	MD	(d)

Table 6.—Net distance traveled and net travel rates for radiotrack segments <50 h long.

Track segment (Fig. 4)	Duration (h)	Minimum distance (n.mi.)	N.mi. h	N.mi. day
1-2 (set)	16	59	3.7	89
2-3 (set)	24	28	1.2	29
3-4 (set)	24	69	2.9	70
4-5	22	75	3.4	82
1-3 (set)	40	70	1.8	43
2-4 (set)	48	80	1.7	41
3-5	46	10	0.2	5
6-7 (chase)	19	60	3.2	77
Average	—	—	2.3	54

400-day returns (15), the logged take of yellowfi within a radius of 250 n.mi. and a radius of 250 n.mi. during the period after 50 days following and before capture, or after 200 days and before ture, respectively (Table 7) (catch of yellowfin tur closest correlate of actual tag recapture effor number of dolphins captured) for which data c cient geographical and temporal precision are able). For both groups of tag returns, the catch of fin tuna in each instance was greater in the 250-

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[5] Unpublished data furnished by J. Joseph, Inter-American Tuna Commission, P.O. Box 271, La Jolla, CA 92038.

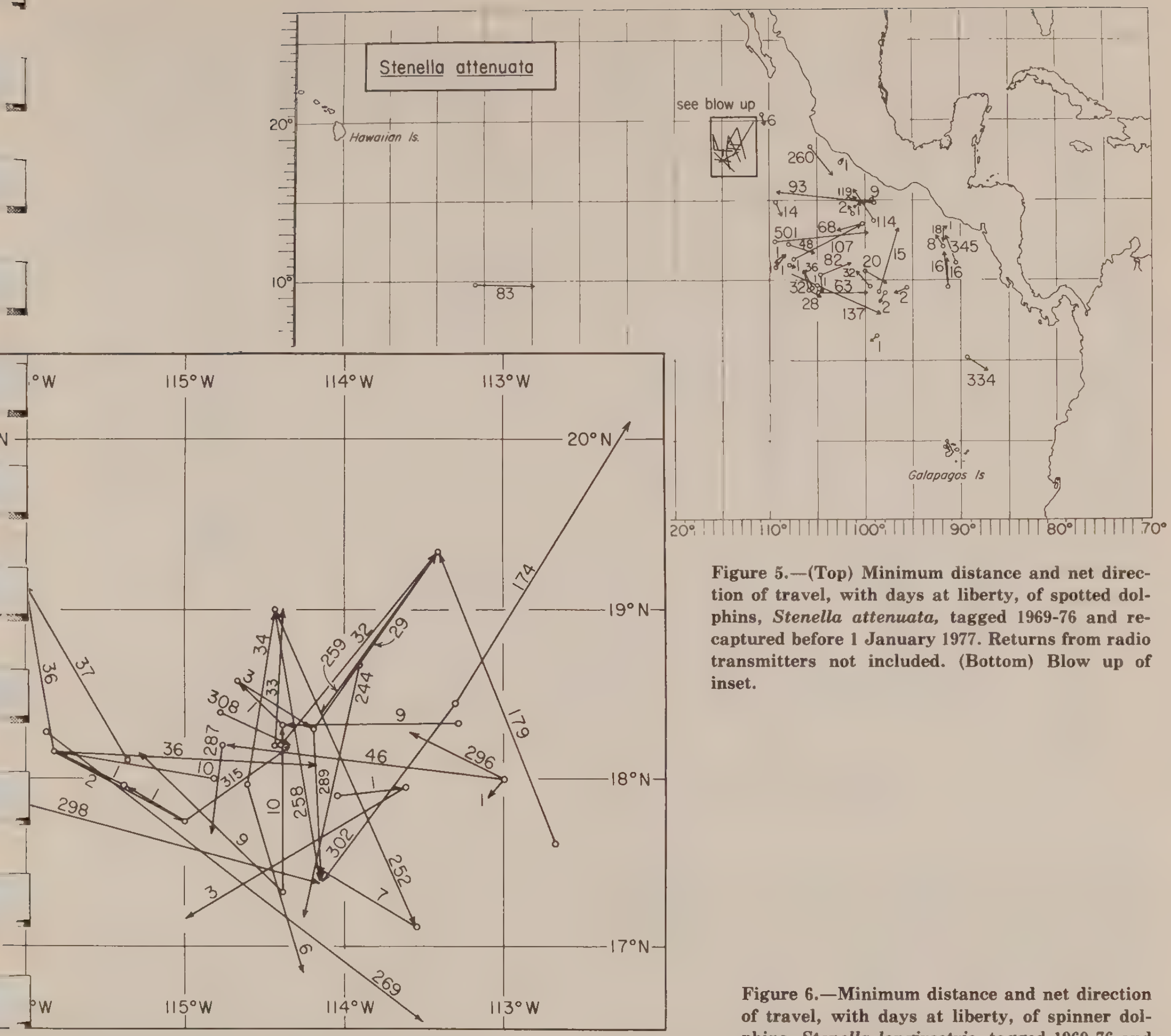
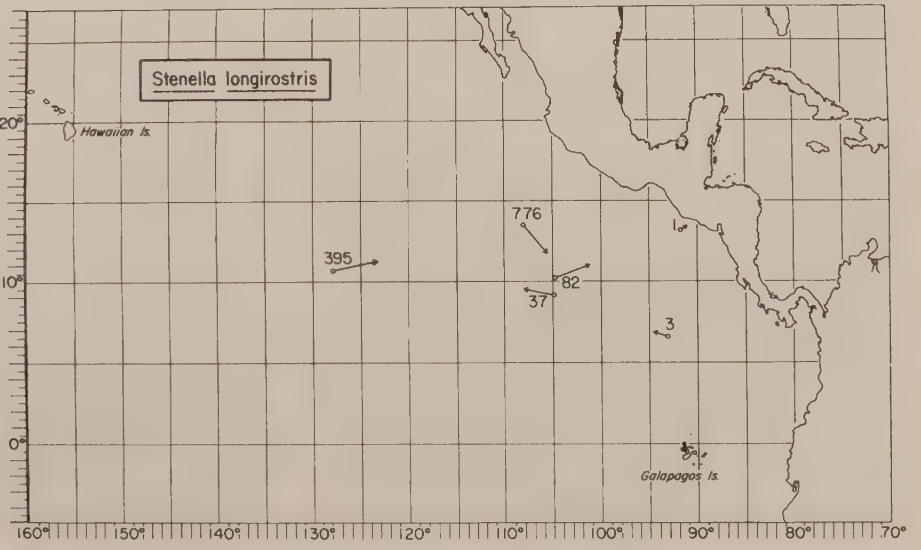

Stenella attenuata
see blow up
Hawaiian Is.
Galapagos Is
20°
10°
83
6
260
1
93
119
9
14
2
114
501
68
48
107
82
15
20
36
32
328
63
28
137
2
1
18
8
345
16
334
20°
110°
100°
90°
80°
70°
115°W
114°W
113°W
20°N
19°N
18°N
17°N
174
179
259
32
29
34
33
37
36
308
244
9
287
46
296
315
10
289
258
298
302
252
7
3
6
269

Figure 5.—(Top) Minimum distance and net direction of travel, with days at liberty, of spotted dolphins, *Stenella attenuata*, tagged 1969-76 and recaptured before 1 January 1977. Returns from radio transmitters not included. (Bottom) Blow up of inset.

Figure 6.—Minimum distance and net direction of travel, with days at liberty, of spinner dolphins, *Stenella longirostris*, tagged 1969-76 and recaptured before 1 January 1977.


Stenella longirostris
Hawaiian Is.
Galapagos Is.
20°
10°
0°
776
395
82
37
1
3
160°
150°
140°
130°
120°
110°
100°
90°
80°
70°

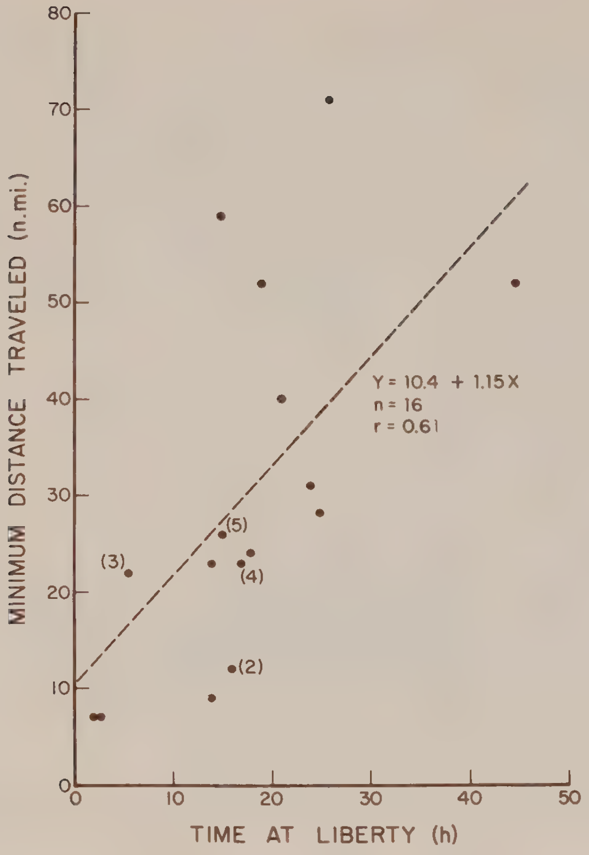


Figure 7.—Movement of tagged spotted dolphins, *Stenella attenuata,* recaptured within 48 h of release. When more than one dolphin was tagged and recovered from the same school at the same time, the number is indicated in parentheses. Dashed line is linear regression line fitted to unweighted data points.

Table 7.—Estimated catch of yellowfin tuna within 250 within 250-600 n.mi. of point of tag release for 12 tagge recovered between 50 and 200 days after release and trav 582 mi (average 174 mi) and 15 tagged dolphins recovere 200 and 400 days after release and traveling <223 mi (mi). Catches for the first group are between 50 days after r before recapture and for the second group between 200 recapture.

Tag returns		Estimated yellowfin tuna c	
		Within 250 n.mi. (short tons)	Within 25 (sho
Group 1			
(50-200 days):	1.	886	1
	2.	9,363	2
	3.	4,858	3
	4.	4,728	3
	5.	76	
	6.	2,065	1
	7.	2,365	
	8.	745	
	9.	516	
	10.	1,202	
	11.	1,436	
	12.	4,737	
Group 2			
(200-400 days):	1.	5,108	
	2.	2,396	2
	3.	470	
	4.	4,656	1
	5.	4,523	1
	6.	3,277	1
	7.	3,893	1
	8.	3,893	1
	9.	4,485	1
	10.	1,955	
	11.	3,051	
	12.	952	
	13.	3,214	
	14.	5,390	1
	15.	759	

Table 8.—Time of year at liberty and net directio movement for seven tagged spotted dolphins, *Ster attenuata,* traveling more than 300 n.mi. be recapture.

At liberty	Net movement	
	Direction	Dista (n.r
1. Jan-May	W	57
2. Aug-Feb	E	56
3. Sept	E	39
4. Nov-Mar	ENE	43
5. Nov-Apr	ESE	58
6.[1] Dec-Feb	E	36

[1]Two dolphins.

n.mi. area than in the 250-n.mi. area. This result shows that the pattern in Figure 8 of apparent annual migration or dispersal of at least some of the tagged animals is real and not an artifact of the distribution of recapture effort.

The net direction of movements of <300 n.mi. was essentially random, but movements >300 n.mi. had a very strong east-west component (Fig. 9). This apparent predominance of longitudinal movement in long-distance returns is probably not due to chance. If it is assumed that the distribution of deviations in Figure 8 would be random, given that neither longitudinal nor latitudinal movement predominate, the probability that all seven of the over 300 n.mi. net movements would have deviations of <20° is described by a binomial probability distribution. If $n = 7$ and $P = 90$, then the probability is 2.6×10^{-5}. The data, therefore, show that, if seasonal migration or dispersal does indeed exist, it is primarily onshore-offshore. The time-of-year data for the few tag returns indicating movements >300 n.mi. indicate that movement may be generally onshore (E) in fall and winter and offshore (W) in late spring and summer (Table 8). This hypothesis must be considered tentative, however, pending availability of mo

In summary, home range at any particular roughly circular, on the order of 200 to 300 diameter, and may move seasonally several miles onshore (possibly in fall and winter) an (possibly in spring and summer). Average short movement is on the order of 30 to 50 n.mi./d

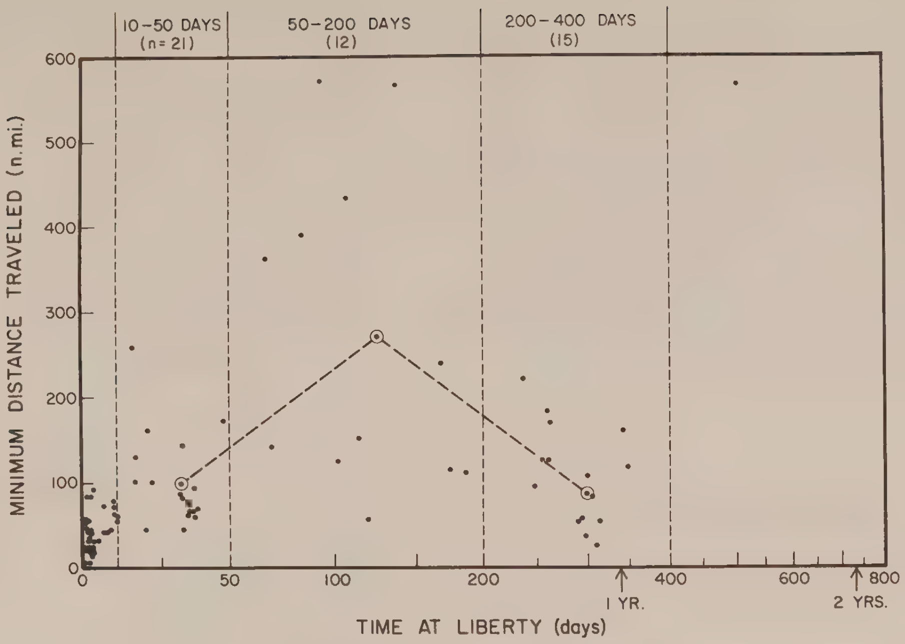


Figure 8.—Plot of minimum distance traveled on time at liberty (logarithmic scale) for tagged and recaptured spotted dolphins, *Stenella attenuata.* Circled means are for 10- to 50-, 50- to 200-, and 200- to 400- day returns.

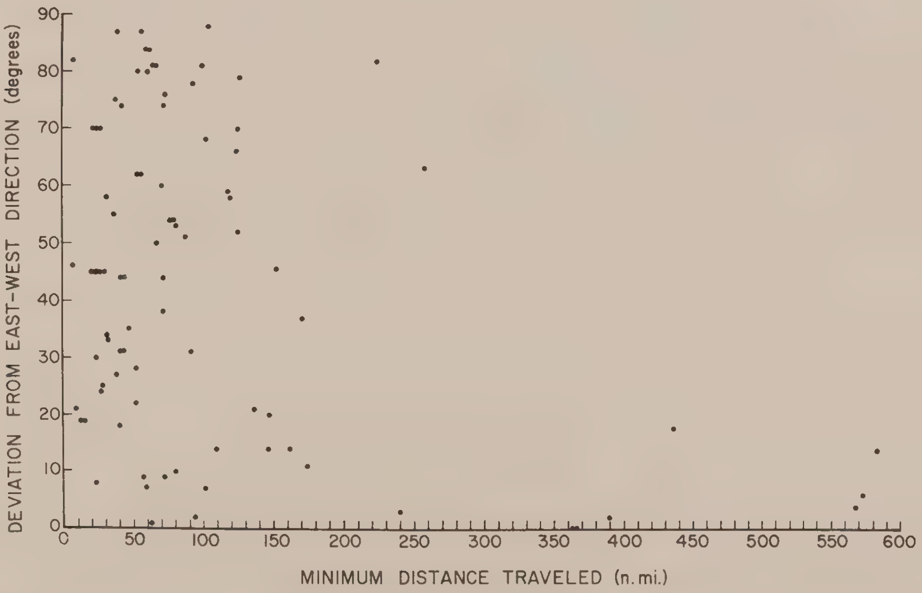


Figure 9.—Deviation from E-W direction of net movement plotted on minimum distance traveled for tagged and recaptured spotted dolphins, *Stenella attenuata.*

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We thank the hundreds of people (scientists, technicians, crew members, and vessel owners and operators) who helped get the tags out and the recoveries in. Some are mentioned in the text; others (including the many "tunaboat observers" who released the tags listed in Appendix 2) are not. We thank W. H. Bayliff who proposed the initial design of the tagging shute. We also thank J. G. Jennings, J. M. Coe, T. Quinn, V. I. Gallucci, R. L. Brownell, Jr., and W. H. Bayliff, for criticizing the manuscript. Unpublished data were furnished by the Inter-American Tropical Tuna Commission through the courtesy of C. J. Orange. R. Butler and N. K. Wiley provided invaluable assistance with data processing.

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December 1979

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Terry L. Leitzell, Assistant Administrator for Fisheries

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Environmental Baselines in Long Island Sound, 1972-73

R. N. REID, A. B. FRAME, and A. F. DRAXLER[1]

ABSTRACT

Quasi-synoptic surveys of water column temperature, salinity, nutrients and dissolved oxygen, sediment grain sizes and organic content, and benthic macrofauna were conducted throughout Long Island Sound in July-August 1972 and April and September 1973. Temperatures were fairly uniform both vertically and horizontally except for some vertical stratification in July-August 1972. Salinities increased gradually from east to west, while depth-related differences were minor. Concentrations of all nutrients measured indicated that inputs at the western end dominated nutrient distributions for the Sound. Dissolved oxygen decreased from east to west and with increasing water temperature. Bottom dissolved oxygen values below 2 mg/liter were recorded at several stations in the western Sound in summer 1972. As a rule, sediments of deep waters in the central and western Sound consisted of silts and clays, whereas sands predominated along the Long Island shoreline and in the eastern basin. Sediment organic matter reached highest values (to 10%) in the westernmost Sound. Three assemblages of benthic macrofauna were identified via cluster analyses of 1972 data: a bivalve (especially *Mulinia lateralis*) dominated group in muddy, deepwater regions; a shallow sandy assemblage in which the bivalves *Spisula solidissima, Tellina agilis,* and *Ensis directus* predominated; and a third assemblage transitional in both sediment characteristics and species composition, but with increased dominance by several polychaete species. The mud-bottom and transitional fauna underwent large decreases in numbers of species and individuals from 1972 to 1973.

INTRODUCTION

ong Island Sound (LIS) is a large (145 km long by 17 km maximum width) estuary bounded on the north by the states of New York and Connecticut and on the south ong Island, N.Y. (Fig. 1). LIS is considered a highly acted estuary (Bowman 1977), having been important for shipping and waste disposal for several centuries. LIS is also heavily used for recreational boating and ming, and supports large recreational (Mohr 1976) an small commercial (McHugh 1977) fisheries.

Several comprehensive studies of the chemical oceanography of LIS exist (Riley et al. 1956, 1959, 1967; Hardy b). Benthic surveys, however, have been limited to rather circumscribed portions of LIS (e.g., Sanders 1956; Michael 1976; McCall 1977; Serafy et al. 1977; Rhoads et 978). Due to their sessile nature and wide variety of istories and tolerances, the benthic macrofauna are particularly suited for biological monitoring of change (Wilhm 1967; Reish 1972; Boesch 1974; Swartz 1978). y are also important as contaminant vectors and as e for resource species.

We therefore felt it would be useful to conduct a synoptic study of the water column chemistry and benthos ghout LIS. This information can serve as a "base- against which to measure future natural fluctuations and anthropogenic impacts.

Our surveys began in the summer of 1972. We sampled ments, benthic macrofauna, and water column temperature, salinity, dissolved oxygen, and nutrients three times (July-August 1972, April and September 1973), and have since surveyed sediments, bottom waters, and macrofauna in September of 1975 and 1976 and July of 1977 and 1978. This report summarizes data from the 1972 and 1973 cruises.

METHODS

We established a total of 142 stations, the majority located every 3-5 km on north-south transects spaced 8.7 km apart (on consecutive 5′ longitude lines) for the length of LIS (Fig. 1). Latitude, longitude, and depth of each station are given in Table 1. Water column, sediment, and macrofauna samples were taken at all stations on the summer 1972 cruise. On subsequent surveys we have resampled bottom waters (+1 m), sediments, and macrofauna from 40 to 95 of these stations. Additional water column sampling was done on the two 1973 cruises. Station locating has been by loran A or C and fathometer, augmented by horizontal sextant, land, and buoy ranges when possible.

On Cruise 1, temperature and salinity were measured at 5 m depth intervals using a Beckman RS-5 induction salinometer. Temperatures were measured with reversing thermometers on Cruises 2 and 3, and a Beckman RS-7B salinometer was used for salinity determinations. Samples for water chemistry analysis were taken 1 m from surface and bottom, using Van Dorn water bottles on Cruise 1 and Niskin bottles on Cruises 2 and 3. Additional water samples were taken at 25 m depth intervals at 15 deepwater stations along the

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[1] Northeast Fisheries Center Sandy Hook Laboratory, National Marine Fisheries Service, NOAA, Highlands, NJ 07732.

Table 1.—Sampling locations and depths, Long Island Sound, 1972-73.

Stn.	Latitude N	Longitude W	Depth (m)	Stn.	Latitude N	Longitude W	Depth (m)	Stn.	Latitude N	Longitude W	Depth (m)	Stn.	Latitude N	Longitude W
1	40°49.1′	73°47.6′	6.1	42	40°59.2′	73°10.0′	25.9	83	41°13.4′	72°45.0′	11.9	123	41°13.1′	72°20.0′
2	40°48.1′	73°41.1′	30.5	43	40°55.8′	73°10.0′	2.4	84	41°11.5′	72°45.0′	18.3	124	41°10.7′	72°20.0′
3	40°48.0′	73°46.3′	4.6	44	41°10.4′	73°05.0′	6.1	85	41°09.1′	72°45.0′	27.5	125	41°08.4′	72°20.0′
4	40°52.8′	73°46.1′	9.2	45	41°07.8′	73°05.0′	12.2	86	41°06.9′	72°45.0′	28.0	126	41°17.0′	72°15.0′
5	40°52.8′	73°45.0′	18.3	46	41°04.9′	73°05.2′	22.9	87	41°04.2′	72°45.0′	29.0	127	41°15.8′	72°15.0′
6	40°52.3′	73°43.4′	4.6	47	41°02.8′	73°05.0′	30.5	88	41°02.0′	72°45.0′	33.6	128	41°13.4′	72°15.0′
7	40°56.3′	73°41.4′	6.1	48	41°00.2′	73°05.0′	36.6	89	41°00.2′	72°45.0′	25.9	129	41°11.2′	72°15.0′
8	40°55.2′	73°41.0′	15.3	49	40°59.1′	73°05.0′	2.4	90	41°58.4′	72°45.0′	5.5	130	41°09.7′	72°15.0′
9	40°53.4′	73°41.0′	10.7	50	41°11.0′	73°03.2′	7.6	91	40°14.9′	72°40.0′	4.6	131	41°18.2′	72°10.0′
10	40°51.8′	73°41.0′	7.6	51	41°11.3′	73°01.8′	9.2	92	41°13.6′	72°40.0′	21.4	132	41°16.2′	72°10.0′
11	40°59.8′	73°35.0′	5.5	52	41°13.1′	73°00.0′	7.6	93	41°11.5′	72°40.0′	27.7	133	41°14.0′	72°10.0′
12	40°58.7′	73°35.0′	18.0	53	41°11.3′	73°00.0′	10.4	94	41°09.1′	72°40.0′	27.7	134	41°11.5′	72°10.0′
13	40°56.4′	73°35.0′	17.7	54	41°09.0′	73°00.0′	15.2	95	41°07.2′	72°40.0′	27.4	135	41°18.2′	72°05.0′
14	40°55.0′	73°35.0′	4.6	55	41°06.2′	73°00.2′	22.9	96	41°04.2′	72°40.0′	24.4	136	41°15.7′	72°05.0′
15	41°00.9′	73°31.6′	6.1	56	41°04.6′	73°00.0′	29.0	97	41°02.1′	72°40.0′	22.9	138	41°18.4′	72°00.0′
16	40°59.8′	73°31.7′	30.5	57	41°01.4′	72°58.6′	30.5	98	41°00.2′	72°40.0′	13.7	139	41°17.5′	72°00.0′
17	40°57.3′	73°31.7′	19.8	58	41°00.1′	73°00.0′	21.9	99	40°59.0′	72°40.0′	4.6	140	41°16.7′	72°00.0′
18	40°55.8′	73°31.7′	5.8	59	40°58.6′	73°00.0′	6.1	100	41°15.8′	72°35.0′	4.6	141	41°19.5′	71°55.0′
19	41°02.6′	73°28.1′	6.1	60	41°14.4′	72°56.6′	4.6	101	41°13.8′	72°35.0′	13.7	142	41°18.6′	71°55.0′
20	41°00.8′	73°28.1′	21.4	61	41°12.6′	72°55.0′	9.2	102	41°10.2′	72°35.0′	27.5	143	41°17.8′	71°55.0′
21	40°58.4′	73°28.3′	21.4	62	41°10.6′	72°55.0′	15.3	103	41°07.8′	72°35.0′	21.4	G1	41°05.6′	72°17.4′
22	40°56.9′	73°28.3′	6.1	63	41°06.3′	72°55.0′	25.0	104	41°04.9′	72°35.0′	21.4	G2	41°08.0′	72°15.0′
23	40°03.3′	73°24.0′	6.1	64	41°04.3′	72°55.0′	28.1	105	41°02.5′	72°35.0′	18.3	G3	41°06.8′	72°15.0′
24	41°02.5′	73°24.0′	15.3	65	41°02.2′	72°55.0′	36.6	106	41°01.4′	72°35.0′	15.3	G4	41°05.5′	72°15.0′
25	40°59.3′	73°23.9′	13.7	66	41°00.3′	72°55.0′	24.4	107	41°00.4′	72°35.0′	4.6	G5	41°04.1′	72°15.0′
26	40°58.1′	73°23.9′	6.1	67	40°58.4′	72°55.0′	6.1	108	41°15.2′	72°30.0′	4.6	G6	41°02.9′	72°15.0′
27	41°06.5′	73°19.5′	7.6	68	41°13.9′	72°52.9′	5.5	109	41°13.3′	72°30.0′	21.4	G7	41°02.2′	72°16.3′
28	41°04.2′	73°19.5′	10.7	69	41°09.0′	72°52.8′	18.9	110	41°10.8′	72°30.0′	30.5	G8	41°01.2′	72°15.0′
29	41°01.0′	73°19.5′	30.5	70	41°08.0′	72°53.9′	21.3	111	41°08.2′	72°30.0′	29.0	G9	41°11.1′	72°10.0′
30	40°58.3′	73°19.5′	16.8	71	40°58.3′	72°52.6′	6.1	112	41°05.6′	72°30.0′	29.0	G10	41°09.2′	72°10.0′
31	40°56.3′	73°19.6′	3.0	72	41°13.6′	72°50.6′	8.5	113	41°03.4′	72°30.0′	3.9	G11	41°08.0′	72°10.0′
32	41°06.9′	73°15.0′	5.5	73	41°12.8′	72°50.0′	12.2	114	41°16.0′	72°25.0′	5.5	G12	41°06.5′	72°10.0′
33	41°05.1′	73°15.0′	17.7	74	41°10.6′	72°50.0′	16.8	115	41°14.9′	72°25.0′	15.3	G13	41°04.4′	72°10.0′
34	41°02.5′	73°15.0′	23.5	75	41°08.6′	72°50.0′	24.4	116	41°13.1′	72°25.0′	24.4	G14	41°03.3′	72°10.0′
35	40°59.8′	73°15.0′	25.9	76	41°06.4′	72°50.0′	29.0	117	41°10.8′	72°25.0′	39.7	G15	41°04.1′	72°07.2′
36	40°57.3′	73°15.0′	16.8	77	41°04.2′	72°50.0′	31.1	118	41°08.4′	72°25.0′	29.0	G16	41°02.7′	72°06.4′
37	40°55.3′	73°15.0′	2.4	78	41°02.2′	72°50.0′	38.1	119	41°06.1′	72°25.0′	16.8	C1	41°16.3′	72°20.4′
38	41°08.7′	73°10.0′	6.1	79	41°00.4′	72°50.0′	31.4	120	41°05.5′	72°25.0′	4.6	C2	41°18.2′	72°21.0′
39	41°06.2′	73°10.0′	12.2	80	40°59.5′	72°50.0′	6.1	121	41°15.7′	72°20.0′	3.7	C3	41°20.2′	72°21.5′
40	41°03.8′	73°10.0′	21.4	81	41°13.6′	72°46.4′	12.2	122	41°14.9′	72°20.0′	9.2			
41	41°01.5′	73°10.0′	29.9	82	41°14.6′	72°45.0′	6.1							

Sound's east-west axis. Dissolved oxygen was determined by the azide modification of the Winkler technique (American Public Health Association 1965), with standard 0.25N phenylarsine oxide substituted for the less stable sodium thiosulfate. Water samples were frozen for later colorimetric determination of nitrate, nitrite, ammonia, urea, iron, and orthophosphorus, using a Technicon Auto Analyser. Nitrate and nitrite were anlyzed using the naphthylenediamine-sulfanilamide system with cadmium reduction of nitrate after Wood et al. (1967). The ammonium analyses, which were based on the phenolhypochlorite Bertelot reaction (Solorzano 1969), were run within 15 days of collection. In some cases this is longer than our tests show is permissible without measurable loss (10 days); however, because of the large area surveyed, shorter intervals were sometimes not possible. The values represent, therefore, a conservative estimate of ammonium concentration. The urea analysis is an adaptation to seawater of Marsh et al.'s (1965) blood urea method in which diacetylmonoxime reacts with urea in the presence of thiosemicarbizide and ferric ion intensifiers. Orthophosph
was measured utilizing the molybdate-ascorbic aci
cedure after Murphy and Riley (1962). Iron was
mined using the essentials of the 2-2′ bipyridal
cedure of Lewis and Goldberg (1954) as adapted t
autoanalyzer by Henriken (1967).

Benthic samples were collected with a 0.1 m^2 S
McIntyre bottom grab. At each station, sediments
one (Cruises 1 and 2) or two (Cruise 3) grabs were si
to 1 mm. Retained macrofauna were relaxed in a m
sium chloride-seawater solution, preserved in
Formalin to seawater mixture and later trasfered to
ethanol with 5% glycerin.

Samples were sorted under dissecting microscope
organisms were identified to species when possible
macrofauna analysis will concentrate on polycha
molluscs, and arthropods, which together comprise
great majorityof species and individuals collected
Call (1977) reported that these three groups acco
for 95% of the infaunal macrobenthos of central LIS)

Species diversity was calculated using the Sha aver (1963) index: $H' = -\sum_{1}^{s} p_i \ln p_i$, where P_i is the proportion of individuals in the *i*th species. H' has two nponents: number of species (S, hereafter termed spe- richness), and equitability ($J' = H'/H'_{\max} = H'/\ln S$) (Lloyd and Ghelardi 1964). Both S and J' were computed for each 0.1 m^2 samples, as was the number of indi- uals (N).

-mode or normal cluster analyses (clustering stations by species) were done by James Archie, State University of New York, Stony Brook. Czekanowski's coeffi- t, $Cz = 2w/a+b$ (Bray and Curtis 1957), was used to sure faunal similarity between each pair of stations. Here a is the sum of abundances of all species found at station A, b is the sum of species abundances for station nd w is the sum of the lower of the abundance values ach species common to A and B. Abundances were log transformed ($\log_e x + 1$), and then single linkage tering was performed via unweighted pair-group hod using arithmetic averages (Sneath and Sokal 197).

Subsamples were taken from the grabs for analyses of ment grain sizes, organics, carbonates, heavy metals, oflora, and meiofauna. The latter three topics were subjects of discrete studies, and their methodologies are described elsewhere (respectively Greig et al. 1977; ey et al. 1977; Tietjen 1977). Sedimentology studies a sediment sample collected from each grab with a 3.7 cm inner diameter coring tube and frozen. Analyses were performed by James Parks and Alex Rugh, Lehigh ersity, Bethlehem, Pa. For grain size analysis, a por- of each core sample was wet-sieved through a 62 μm screen, with retained materials then sieved through a series of 12 screens with meshes from 4 mm to 62 μm. te analysis was used to determine the clay and fine- and coarse-silt fractions of the <62 μm portion. Organic content was determined by weight loss of dried samples treatment with 10% hydrogen peroxide.

RESULTS AND DISCUSSION

nperature and Salinity

Temperature and salinity on Cruises 2 and 3 followed cted patterns, as described by Riley (1955), Riley et 1952, 1956), Hardy (1970, 1972a, b), and Hardy and Weyl (1970). Temperatures were quite uniform both vertically and horizontally in April 1973 (Figs. 2,3), with all es between 4° and 9°C. In late September 1973 tem- tures ranged from 14° to 22°C (Figs. 4, 5), and generally increased from east to west, with the exception of colder water near the Connecticut River. Again, no pro- nced vertical stratification was observed. The vertical uniformity of temperatures (and moderate bottom dissolved oxygen concentrations, as mentioned below) ate that mixing of the water column was already underway by late September.

Hardy (1972b) noted that a thermocline develops in midsummer, especially in the central basin; thermal ing is also seen in our measurements for July and August 1972 (Figs. 6, 7). These Cruise 1 data will not be used in examining horizontal patterns, since the sampling period covered 6 wk, and effects of Hurricane Agnes may have obscured the typical distributions. Reflecting the storm's freshwater input, salinity (Figs. 8, 9) was below 22‰ for most surface waters in central LIS, and down to 17.8‰ at station 28 (Fig. 1), a mile south of the Saugatuck River mouth.

Salinity on Cruises 2 (Figs. 10, 11) and 3 (Figs. 12, 13) increased gradually from west to east (from 23 to 29.6‰ in April and 25.0 to 30.6‰ in September). There were only small increases in salinity with depth during this sampling period.

Nutrients

Distributions of all nutrients measured in summer 1972 exhibit basically a single pattern: very large inputs from the East River at the western end of the Sound dominate nutrient distributions and water quality throughout western LIS. Surface ammonium, for instance, approaches 30 microgram-atoms/liter (μgat/liter) at Throgs Neck (Fig. 14). These high levels agree with those reported for August of the previous year by Hardy (1972b). His study showed that to the west ammonium concentrations increased in the East River, to the west of Throgs Neck; a tenfold decrease in surface ammonium is evident from Throgs Neck to just east of Hempstead Harbor (stations 7-10, Fig. 1). Open surface waters of the central basin (as defined by Hardy 1972b) had moderate ammonium levels (generally 0.5-1.0 μgat/liter). The Long Island coast east of long. 73°10'W (stations 38-43 in Fig. 1) showed similar concentrations. The eastern end of the Sound was characterized by ammonium values of <0.5 μgat/liter, again in agreement with Hardy (1972b). There appear to be ammonium additions in the areas off New Haven-West Haven, Oyster Bay-Northport, and the Nissequogue River (station 37), and perhaps off New London and Bridgeport. Ammonium is also presumably being added in the densely populated western end, but this cannot be distinguished from the East River input.

Bottom ammonium (Fig. 15) was also most elevated in the western end, with values higher than in surface waters except at Throgs Neck. According to the bottom ammonium values, the "plume" of East River water extended east to the Oyster Bay-Stamford transec.

Surface nitrate (Fig. 16) showed much the same pattern as ammonium, with most conspicuous inputs from the East River, Bridgeport, New Haven, and New London. Bottom concentrations (Fig. 17) were greatest from Hempstead Harbor to Throgs Neck, and off New Haven; other areas with high surface nitrates did not show comparable levels in bottom waters. Nitrite (Figs. 18, 19) and orthophosphorus (Figs. 20, 21) distributions also had as their most significant feature elevated values in western LIS. As a rule, noticeably elevated concentrations were confined to waters west of long. 73°25' (Lloyd Neck). Values in microgram-atoms per liter for these three nutrients ranged from undetectable to: surface nitrate, 2.76; bottom nitrate, 2.64; surface nitrite, 3.53;

bottom nitrite, 3.55; surface orthophosphate, 6.90; bottom orthophosphate, 6.14.

In April 1973, ammonium concentrations (Figs. 22, 23) were much lower at Throgs Neck than during the previous summer, and the decrease moving eastward was much less marked, with values at the eastern end slightly higher than for Cruise 1. Nitrate levels (Figs. 24, 25) were somewhat above those measured on Cruise 1, with extremely high concentrations (to 41.6 μgat/liter) at the mouth of the Connecticut River during this period of high runoff. Orthophosphorus (Figs. 26, 27) was low and uniform, varying between 0.4 and 1.0 μgat/liter except for values of 1.0 to 2.7 from Hempstead Harbor west. Nitrite (Figs. 28, 29) was lower than the previous summer; large portions of central and eastern LIS contained <0.1 μgat/liter.

On Cruise 2 we added urea determinations to our nutrient measurements in an effort to better determine the effects of sewage additions on LIS's nutrient patterns. Urea concentrations in April 1973 (Figs. 30, 31) were found to be <1 μgat/liter for most of LIS. As expected, the higher values were found in the western end, again most noticeably from Stamford and Hempstead Harbor west. The maximum concentration was 3.24 μgat/liter at Throgs Neck. This was somewhat higher than that measured by Hardy (1972b) in this area in April 1971. Hardy found that urea concentrations continued to increase in the East River, with a maximum of >6 μgat/liter in the lower river.

The Connecticut River and its plume into LIS had elevated urea concentrations as did a large area roughly between Bridgeport, New Haven, and Port Jefferson.

Dissolved Oxygen

Dissolved oxygen (DO) levels showed a strong inverse relationship to nutrient concentrations in summer 1972. Surface DO's (Fig. 32) were depressed, and bottom concentrations (Fig. 33) markedly so, in extreme western LIS. Surface values were >7 mg/liter through most of eastern and central LIS. DO declined sharply from approximately Hempstead Harbor west, falling from 8 to <3 mg/liter within 7 n.mi. Lesser DO depressions were evident off the Saugatuck River and in the areas of Bridgeport, New Haven, New London, and Huntington Bay (stations 22, 26). A significant feature of surface DO distributions was the appearance of supersaturated areas off Hempstead Harbor, Stamford, and between Bridgeport and Port Jefferson. Hardy and Weyl (1971) reported similar findings for August 1970. They attributed the observed pattern to phytoplankton blooming in response to the high nutrient levels in this area. West of the DO maxima, phytoplankton standing crops may be reduced by inhibition from East River sewage effluents (Hardy 1972b), or perhaps by light limitation or a necessary incubation period prior to blooming.

Bottom DO's (Fig. 33) were above 5 mg/liter for most of the central basin, and >7 in the eastern sector. They fell below 5 mg/liter in deep waters west of New Haven, <4 mg/liter west of Stamford, and <3 mg/liter past Hempstead Harbor. There were scattered areas of
greater depletion, with 1.7 and 1.8 mg/liter at two
tions (9 and 10) in the Hempstead Harbor area, anc
near the mouth of the Saugatuck River (station 27).
oxygen levels in western LIS bottom waters during s
mer have been reported previously (Hardy and V
1971). An earlier survey of this area (National Ma
Fisheries Service[2]) revealed the entire western en
have its lowest bottom DO's (1.0 mg/liter at Th
Neck; 0.7 at Hempstead Harbor's mouth) coinci
with highest summer temperatures. In the present
vey, the Connecticut shoreline in the Bridgeport-
Haven region also showed somewhat depressed bot
DO.

The low DO's described above are of course a seas
phenomenon. In April 1973, after a lengthy period of
temperatures and wind-generated mixing, DO's
risen above 10 mg/liter for the entire Sound (Figs. 34,
Our September 1973 data (Figs. 36, 37) indicate
rapidity with which oxygen levels in the western So
can change. Samples taken on 12 and 13 September
again revealed the characteristically low values ass
ated with western LIS during the warmer months.
weeks later, however, bottom DO's had increased to
mg/liter at Throgs Neck and >6 everywhere else.
dramatic improvement was again probably relate
wind-generated mixing. Hardy and Weyl (1971) ag
that winds can have a controlling effect on DO con
trations in western LIS.

Sediments

Figure 38 shows distribution of silts and clays (<6
diameter) in surface sediments for summer 1972,
on means of two cores analyzed per station. Sedin
over large portions of central and western LIS, espec
in deeper waters but also along portions of the Conn
cut coast, consist predominantly of fine materials
95% silt/clay). These soft-bottom areas are interru
by strips or patches of coarser sediments in several
of LIS, generally corresponding to shoaler areas. Co
materials (≤5% silt/clay) are also found in shallow
for the entire length of the Long Island coast. The
tively coarse sediments extend into deeper waters (
m) atop Mattituck Sill, a submarine ridge separ
eastern LIS from the remaining two-thirds of the S
(Hardy 1972b). The well-flushed eastern basin has
ly coarse sediments.

Sediment Heavy Metals, Microorganisms

As mentioned earlier, distributions of sediment h
metals and fecal coliform bacteria have been desc
elsewhere. To summarize: heavy metal and colifor
tributions were in general agreement with the dist
tions of nutrients and dissolved oxygen described a

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[2] National Marine Fisheries Service. 1972. Davids Island Pha
short-term ecological survey of western Long Island Sound.
Atlantic Coastal Fisheries Center, Informal Rep. 7, 29 p.

ncentrations in the extreme western end of LIS were almost invariably orders of magnitude higher than levels in the eastern basin. Most of the northern Long Island reline was also low in sediment heavy metals and l coliforms. Deep waters in central LIS showed intermediate values, while several areas near population and industrial centers on the Connecticut coastline had levels ost as high as were found at the western end.

Sediment Organic Matter

istribution of sediment organic matter for Cruise 1 (Table 2) showed a pattern similar to that for the above water and sediment constituents. Much of LIS, especial- long the Long Island coast and in the eastern basin, <1% organic matter in sediments. The highest values were found from the station 7-10 transect (long. 73°40′W) west. Stations 1, 5, and 7 in westernmost LIS between 9 and 10% organics in sediment. Highly nic sediments were also found in a band between long. 73°10′ and 73°20′W, and in several other patches of mostly deepwater, muddy sediments in the central n. Table 2 also indicates substantial between-cruise ability in sediment organics at a number of stations. This is undoubtedly due in part to sediment patchiness and/or station relocation inaccuracies.

Benthic Macrofauna

A list of all annelids, molluscs, and arthropods collected during our most extensive (summer 1972) sampling is given in Table 3. We identified a total of 248 species within these taxa, with annelids accounting for 46% of the species, molluscs 21%, and arthropods 33%.

Shannon-Weaver species diversities (*H′*) were calculated for all 1972 samples. Distribution of *H′* values is shown in Figure 39. An obvious feature of the *H′* distributions is that lowest values (<1.0 bits/individual) were found amost exclusively at deepwater stations with high silt-clay content (compare with Fig. 38). Low diversities in these areas were due mostly to a high degree of dominance by several bivalve species, as will be discussed below. In the central and western basins there was no apparent reduction of *H′* values with the higher levels of pollution found toward the western end of LIS. Highest diversities, however, were found in the eastern basin, which also had lowest contaminant levels.

Table 2.—Organic matter in Long Island Sound sediments (weight percent).

Station	Cruise			Station	Cruise			Station	Cruise			Station	Cruise		
	1	2	3		1	2	3		1	2	3		1	2	3
1	9.54		4.67	37	0.03	0.02	0.56	73	0.51		0.57	109	0.50		
2	0.26	6.83	5.15	38	0.16			74	0.53			110	0.10		0.00
3	0.54		3.30	39	0.09			75	5.86			111	0.13		0.57
4	0.35		0.34	40	0.42			76	0.46			112	4.37		
5	9.05	1.23	1.10	41	0.01			77	0.25			113	0.12		
6	0.08	0.33	0.61	42	7.36			78	0.52			114	0.64	0.35	1.34
7	9.96	0.41	4.31	43	0.16			79	0.74			115	0.11		0.70
8	1.14	0.01	1.35	44	0.17	1.38	2.48	80	0.01			116	0.02	0.09	0.00
9	0.35	1.58	0.00	45	0.10		6.23	81	0.14	0.90	3.37	117	0.06	0.01	0.42
10	5.44	0.11	0.94	46	0.37	0.01	2.22	82	1.46	2.42	4.14	118	0.15	0.04	0.57
11	0.74	0.13	0.26	47	0.39	0.18	1.68	83	0.09			119	0.17		0.98
12	0.41	1.66	6.66	48	2.13			84		7.61	3.54	120	0.11	0.08	0.80
13	0.10	0.05	6.17	49	0.09	0.05	0.76	85	3.24			121	0.35		0.43
14	0.23	0.52		50	0.10	0.14	1.21	86	0.29	1.57	3.19	122	0.03		
15	0.00		0.47	51	0.16	0.19	0.80	87	1.68			123	0.05		0.37
16	1.39	0.39	0.55	52	0.54			88	3.62	1.08	3.96	124	0.15		
17	0.79	1.61	0.93	53	0.32			89	2.49			125	0.26		0.79
18	0.23	0.07	0.51	54	0.06			90	0.28	0.27	0.80	126	0.51	0.23	1.38
19	0.53	0.64	0.30	55	2.15	0.60	3.38	91	0.48			127	0.68	0.06	1.34
20	2.26		6.79	56	3.04			92	0.23			128	0.05	0.04	0.65
21	0.42			57	1.99	0.12	0.51	93	0.29			129	0.13		0.87
22	0.18		4.11	58	0.66			94	2.82			130	0.18	0.02	0.48
23	0.18	0.04	1.15	59	0.02			95	0.30			131	0.19		1.10
24	0.35		2.46	60	1.22	1.99	5.96	96	0.21			132	0.38		0.55
25	0.26	0.31	2.46	61	0.22	2.18	0.86	97	0.16			133	0.91		0.50
26	0.13	0.03	0.79	62	0.02	0.50	1.18	98	0.24			134	0.11		0.52
27	0.08		0.92	63	0.27	0.30	1.45	99	0.06			135	1.28	0.43	0.45
28	0.53		0.57	64	1.13			100	1.46	1.94	3.07	136	1.17	0.05	1.04
29	1.05	2.38		65	0.97	1.42	6.98	101	0.07		0.94	138	0.08		
30	1.12		3.90	66	1.07			102	0.06	0.09	0.39	139	0.08		1.15
31	0.03		0.62	67	0.11	0.03	0.39	103	0.06	0.02	1.06	140	0.20		1.73
32	0.10	0.01	2.15	68	0.69	0.01	0.52	104	0.07		0.83	141	0.44		0.73
33	8.18			69	0.44	1.03	0.62	105	0.40	0.16	1.40	142	0.21		
34	1.26	0.06	0.53	70	0.46	0.70	4.64	106	1.48			143	0.27		
35	4.96	1.00	0.35	71	0.12	0.23		107	0.12		0.78				
36	1.18	0.56	1.08	72	0.95	0.45	3.20	108	1.44						

Table 3.—Benthic macrofauna species collected in Long Island Sound, 1972-73.

- POLYCHAETA
  - POLYNOIDAE
    - *Harmothoe extenuata*
    - *Harmothoe imbricata*
    - *Lepidonotus squamatus*
    - *Lepidonotus sublevis*
  - SIGALIONIDAE
    - *Sthenelais boa*
    - *Sthenelais limicola*
    - *Sigalion arenicola*
    - *Pholoe minuta*
  - PHYLLODOCIDAE
    - *Eteone heteropoda*
    - *Eumida sanguinea*
    - *Paranaitis speciosa*
    - *Phyllodoce arenae*
    - *Phyllodoce mucosa*
    - *Phyllodoce maculata*
  - HESIONIDAE
    - *Podarke obscura*
  - PILARGIDAE
    - *Cabira incerta*
    - *Sigambra tentaculata*
  - SYLLIDAE
    - *Proceraea cornuta*
    - *Autolytus verrilli*
    - *Autolytus* #1
    - *Odontosyllis fulgurans*
    - *Brania clavata*
    - *Brania* #2
    - *Exogone dispar*
    - *Exogone naidina*
    - *Parapionosyllis longicirrata*
    - *Syllides* #1
    - *Syllides* #2
    - *Typosyllis* #1
    - *Syllis gracilis*
    - *Syllis spongiphila*
    - *Sphaerosyllis erinaceus*
  - NEREIDAE
    - *Nereis acuminata*
    - *Nereis grayi*
    - *Nereis succinea*
    - *Nereis zonata*
  - NEPHTYIDAE
    - *Nephtys bucera*
    - *Nephtys incisa*
    - *Nephtys picta*
  - GLYCERIDAE
    - *Glycera americana*
    - *Glycera dibranchiata*
  - GONIADIDAE
    - *Goniadella gracilis*
  - SCALIBREGMIDAE
    - *Scalibregma inflatum*
  - OPHELIIDAE
    - *Travisia carnea*
  - CAPITELLIDAE
    - *Capitella capitata*
    - *Heteromastus filiformis*
    - *Notomastus luridus*
    - *Mediomastus ambiseta*
  - MALDANIDAE
    - *Clymenella zonalis*
    - *Clymenella torquata*
    - *Asychis elongata*
    - *Nicomache lumbricalis*
  - PARAONIDAE
    - *Aricidea catherinae*
    - *Paraonis gracilis*
    - *Paraonis lyra*
  - SPIONIDAE
    - *Polydora ligni*
    - *Polydora websteri*
    - *Polydora socialis*
    - *Polydora colonia*
    - *Polydora quadrilobata*
    - *Prionospio steenstripi*
    - *Scolecolepides viridis*
    - *Scolelepis (Scolelepis) squamata*
    - *Scolelepis (Nerinides)* # 1
    - *Spio filicornis*
    - *Spiophanes bombyx*
    - *Streblospio benedicti*
    - *Pygospio elegans*
    - *Spiochaetopterus oculatus*
    - *Boccardia* #1
  - SABELLARIIDAE
    - *Sabellaria vulgaris*
  - ONUPHIDAE
    - *Diopatra cuprea*
  - EUNICIDAE
    - *Marphysa sanguinea*
    - *Marphysa belli*
  - LUMBRINERIDAE
    - *Lumbrineris tenuis*
    - *Lumbrineris fragilis*
    - *Ninoe nigripes*
  - ARABELLIDAE
    - *Arabella iricolor*
    - *Drilonereis longa*
    - *Notocirrus spiniferus*
  - DORVILLEIDAE
    - *Schistomeringos longicornis*
    - *Schistomeringos caeca*
    - *Protodorvillea gaspiensis*
  - ORBINIIDAE
    - *Orbinia ornata*
    - *Orbinia swani*
    - *Scoloplos armiger*
    - *Haploscoloplos fragilis*
    - *Haploscoloplos robustus*
  - CIRRATULIDAE
    - *Cirratulus grandis*
    - *Tharyx annulosus*
    - *Tharyx acutus*
    - *Dodecaceria coralii*
    - *Caulleriella cf killariensis*
  - OWENIIDAE
    - *Owenia fusiformis*
  - PECTINARIIDAE
    - *Pectinaria gouldii*
  - AMPHARETIDAE
    - *Asabellides oculata*
    - *Melinna cristata*
    - *Ampharete arctica*
    - *Amage auricula*
  - TEREBELLIDAE
    - *Loimia medusa*
    - *Pista cristata*
    - *Pista maculata*
    - *Polycirrus eximius*
    - *Polycirrus medusa*
    - *Polycirrus phosphoreus*
    - *Nicolea venustula*
  - FLABELLIGERIDAE
    - *Pherusa affinis*
    - *Brada granosa*
    - *Brada villosa*
  - SABELLIDAE
    - *Potamilla reniformis*
    - *Sabella microphthalma*
    - *Euchone elegans*
    - *Laonome kroyeri*
  - SERPULIDAE
    - *Hydroides dianthus*
- GASTROPODA
  - CALPTRAEIDAE
    - *Crepidula fornicata*
    - *Crepidula plana*
  - NATICIDAE
    - *Polinices duplicatus*
    - *Lunatia heros*
    - *Natica pusilla*
    - *Naticid* #1
  - MURICIDAE
    - *Eupleura caudata*
    - *Urosalpinx cinerea*
  - COLUMBELLIDAE
    - *Anachis translirata*
    - *Mitrella lunata*
  - MELONGENIDAE
    - *Busycon canaliculatum*
  - NASSARIIDAE
    - *Nassarius trivittatus*
  - ACTEONIDAE
    - *Acteon punctostriatus*
  - SCAPHANDRIDAE
    - *Cylichna oryza*
  - PHILINIDAE
    - *Philine sinuata*
  - ACTEOCINIDAE
    - *Acteocina canaliculata*
  - PYRAMIDELLIDAE
    - *Odostomia* #1
    - *Turbonilla elegantula*
    - *Turbonilla sumneri*
  - ONCHIDORIDAE
    - *Onchidoris aspersa*
- PELECYPODA
  - SOLEMYIDAE
    - *Solemya velum*
  - NUCULIDAE
    - *Nucula proxima*
    - *Nucula delphinodonta*
    - *Yoldia limatula*
  - ARCIDAE
    - *Anadara transversa*
  - MYTILIDAE
    - *Mytilus edulis*
    - *Modiolus modiolus*
    - *Musculus corrugatus*
    - *Crenella glandula*
  - ANOMIIDAE
    - *Anomia simplex*
  - OSTREIDAE
    - *Crassostrea virginica*
  - ASTARTIDAE
    - *Astarte castanea*
    - *Astarte undata*
    - *Astarte quadrans*
  - CARDITIDAE
    - *Cyclocardia borealis*
  - MONTACUTIDAE
    - *Mysella planulata*
  - CARDIIDAE
    - *Cerastoderma pinnula*
  - VENERIDAE
    - *Mercenaria mercenari*
    - *Pitar morrhuana*
    - *Gemma gemma*
  - PETRICOLIDAE
    - *Petricola pholadiform*
  - TELLINIDAE
    - *Tellina agilis*
  - PERIPLOMATIDAE
    - *Periploma papyratium*
  - SOLENIDAE
    - *Ensis directus*
  - MACTRIDAE
    - *Spisula solidissima*
    - *Mulinia lateralis*
  - HIATELLIDAE
    - *Hiatella arctica*
  - MYACIDAE
    - *Mya arenaria*
  - CORBULIDAE
    - *Corbula contracta*
  - LYONSIIDAE
    - *Lyonsia hyalina*
  - PANDORIDAE
    - *Pandora gouldiana*
- PYCNOGONIDA
  - PHOXICHILIDIIDAE
    - *Anoplodactylus lentu*
  - AMMOTHEIDAE
    - *Achelia spinosa*
  - NYMPHONIDAE
    - *Nymphon grossipes*
- CUMACEA
  - LEUCONIDAE
    - *Leucon americanus*
    - *Eudorella pusilla*
  - DIASTYLIDAE
    - *Oxyurostylis smithi*
    - *Diastylis sculpta*
- TANAIDACEA
  - PARATANAIDAE
    - *Leptognatha caeca*
- ISOPODA
  - IDOTEIDAE
    - *Chiridotea tuftsi*
    - *Erichsonella filiformi*
    - *Edotea triloba*
  - ANTHURIIDAE
    - *Cyathura polita*
    - *Ptilanthura tenuis*
    - *Ananthura* #1
  - CIROLANIDAE
    - *Cirolana polita*
    - *Cirolana burbancki*
- AMPHIPODA
  - AMPELISCIDAE
    - *Ampelisca abdita*
    - *Ampelisca vadorum*
    - *Ampelisca verrilli*
    - *Ampelisca macroceph*
    - *Byblis serrata*
  - AMPITHOIDAE
    - *Ampithoe longiman*
  - AORIDAE
    - *Lembos websteri*

le 3.—Continued.

Leptocheirus pinguis
Microdeutopus gryllotalpa
Microdeutopus anomalus
Pseudunciola obliquua
OROPHIIDAE
Cerapus tubularis
Corophium acherusicum
Corophium tuberculatum
Corophium crassicorne
Corophium bonelli
Erichthonius brasiliensis
Unciola inermis
Unciola irrorata
Unciola serrata
Unciola dissimilis
GAMMARIDAE
Elasmopus levis
Gammarus mucronatus
AUSTORIIDAE
Acanthohaustorius millsi
Bathyporeia parkeri
Parahaustorius attenuatus
Parahaustorius holmesi
Protohaustorius deichmannae
Protohaustorius wigleyi
Acanthohaustorius n. sp. #1
Acanthohaustorius n. sp. #2
AEIDAE
Photis dentata
ISCHYROCERIDAE
Jassa falcata
LJEBORGIIDAE
Listriella barnardi
Sextonia americana
LYSIANASSIDAE
Lysianassa alba
Psammonyx nobilis
Orchomenella pinguis
OEDICEROTIDAE
Synchelidium americanum
PHOXOCEPHALIDAE
Paraphoxus spinosus
Phoxocephalus holbolli
Trichophoxus epistomus
PLEUSTIDAE
Stenopleustes gracilis
Stenopleustes inermis
Pleusymtes glaber
CAPRELLIDAE
Aeginina longicornis
Caprella unica
Caprella penantis
Paracaprella tenuis
Luconacia incerta
DECAPODA
HIPPOLYTIDAE
Eualus pusiolus
CRANGONIDAE
Crangon septemspinosa
THALASSINIDEA
Callianassa atlantica
Axius #1
PAGURIDAE
Pagurus longicarpus
Pagurus pollicaris
PORTUNIDAE
Ovalipes ocellatus
CANCRIDAE
Cancer borealis
Cancer irroratus
XANTHIDAE
Neopanope texana sayi
Xanthid #1
PINNOTHERIDAE
Dissodactylus mellitae
Pinnotheres maculatus
Pinnixa #1
MAJIDAE
Libinia dubia
Libinia emarginata

The cluster analysis of 1972 faunal data revealed one e group of 43 stations (Fig. 40) with relatively homo- eous fauna (similarity ≥50%). This group occurred mostly in muddy, deepwater sediments throughout central and western LIS; 37 of the stations had ≥69% /clay, and 38 were ≥15 m deep. Table 4 lists the fauna ical of these fine sediments in 1972, giving mean densities per square meter as well as coefficient of varia- (standard deviation ÷ mean density × 100) and fre- ncy of station occurrences for each of the 17 species found at a majority of the 43 stations (an 18th species, the anthozoan *Ceriantheopsis americana,* was present in ajority of samples analyzed for April and September 3 though not for 1972). The 1972 mud-bottom assemblage was dominated by small bivalves, including *Nucula proxima* and *Yoldia limatula* (burrowing deposit ers), *Pitar morrhuana,* and especially *Mulinia later-* (suspension feeders). Other very frequently occurring constituent species were the polychaete *Nephtys incisa* (burrowing deposit feeder), and gastropods *Nassarius ttatus* (surface deposit feeder) and *Acteocina canali- ta* (carnivore). Overall faunal density was extremely high ($\bar{x}$ = 10,400/m^2). Diversity was quite low, due to low species richness and dominance by *Mulinia.* As indicated by frequencies of occurrence and coefficients of variation, *Nephtys, Nassarius, Acteocina, Mulinia,* and *Pitar* had relatively even abundances in the mud-bottom areas; distributions of the remaining species were patchier.

Table 4 also lists mean densities, coefficients of variation, and frequencies of occurrence of these 18 species based on the more limited data available for April 1973 (one sample from each of 13 stations) and September 1973 (16 samples, 13 stations; these stations were fairly evenly distributed over the area in which the mud assemblage was present in 1972, as was also the case for 1973 sampling in the sand and transitional assemblages discussed below).

Numbers of individuals and species declined precipitously from summer 1972 to April 1973, and no recovery was apparent by September 1973. The decline affected almost all taxa; only the anthozoan *Ceriantheopsis,* polychaetes *Nephtys* and *Pherusa,* and bivalve *Nucula* showed September 1973 densities greater than or equal to two-thirds as high as their summer 1972 values. Species diversity and equitability increased, reflecting the reductions in populations of dominants such as *Mulinia* and *Pitar.* This "population crash" had been reported for portions of central LIS (McCall 1977), but its areal extent had not been delimited. Our evidence indicates that the decline extended over the entire area containing the mud assemblage (Fig. 40) with the following exceptions: the westernmost station (5) had slightly increased numbers of individuals and species in 1973, though *Mulinia* and *Pitar* were replaced as dominant species by several polychaetes and *Ceriantheopsis;* station 72, in relatively shallow water near New Haven, also had a shift in species composition toward polychaetes with little change in overall faunal density or species richness; while station 86, the easternmost mud bottom area for which we have 1973 data, contained a typical *Mulinia* assemblage in April 1973, but *Mulinia* had disappeared and overall numbers of species and individuals were greatly reduced by September 1973.

A somewhat less widespread, more variable faunal assemblage, found at 12 stations with faunal similarity ≥37%, occurred primarily along the Long Island coast, in sandy sediments at shallow depths (Fig. 40). All stations in this group contained ≤3.7% silt/clay, and all were in water ≤6.1 m deep. This group of stations thus represents the other extreme of soft-bottom habitat types among our LIS samples. Only 15 species were present at ≥50% of the 12 stations in 1972 (Table 5) though overall species richness (and diversity) were considerably greater than in mud bottoms. The assemblage was dominated by three suspension-feeding bivalves, *Tellina agilis, Ensis directus,* and *Spisula solidissima.* Other prominent members were *Nephtys picta* and *Nassarius trivittatus* as well as a suspension-feeding gastropod, *Crepidula fornicata,* and the omnivorous hermit crab, *Pagurus longicarpus.*

Based on the few samples processed from September 1973 (Table 5), this habitat did not experience a faunal decline comparable with that described above for the

Table 4.—Average densities/m² ($\bar{x}$), coefficients of variation (CV), and frequencies of occurrence (F) of species commonly found in muddy, deep-water sediments in Long Island Sound, 1972-73.

	Summer 1972 n=43 stations			April 1973 n=13			September 1973 n=13(16 samples)		
	$\bar{x}$	CV,%	F,%	$\bar{x}$	CV,%	F,%	$\bar{x}$	CV,%	F,%
ANTHOZOANS									
Ceriantheopsis americana	14	151	44	14	128	62	58	237	56
POLYCHAETES									
Nephtys incisa	60	68	98	90	72	100	100	92	88
Pherusa affinis	50	122	77	14	105	62	45	290	50
Polydora ligni	157	291	74	1	350	8	2	211	19
Asychis elongata	18	212	56	12	120	54	7	181	31
GASTROPODS									
Nassarius trivittatus	101	77	98	61	104	85	55	99	94
Cylichna oryza	31	139	58	0	—	0	0	—	0
Acteocina canaliculata	179	82	93	12	288	23	0	—	0
PELECYPODS									
Nucula proxima	483	222	70	402	241	62	324	216	81
Yoldia limatula	191	155	93	4	134	38	51	267	56
Pitar morrhuana	357	72	95	29	170	62	4	143	38
Mulinia lateralis	8,217	61	100	710	325	54	11	276	19
Lyonsia hyalina	29	196	61	0	—	0	2	395	6
Pandora gouldiana	47	169	61	4	295	20	0	—	0
CRUSTACEANS									
Oxyurostylis smithi	17	139	63	0	—	0	0	—	0
Ampelisca abdita	53	132	70	0	—	0	26	275	25
Crangon septemspinosa	12	123	63	1	350	8	5	126	44
Cancer irroratus	7	115	54	1	350	8	1	417	6
[1]Total individuals/m²	10,400	56		1,469	181		1,263	136	
[1]Total species	21.2	31		9.6	42		10.1	65	
[1]Species diversity, H'	1.07	52		1.47	45		1.46	36	
[1]Equitability, J'	0.35	51		0.67	37		0.69	33	

[1] Means for entire samples, including rarer species.

finer-sediment assemblage. Mean species richness, diversity, and equitability were almost identical between the two samplings. Mean faunal density did show a large drop in 1973; however, the high 1972 mean density had been due mostly to a large population of a small bivalve, *Gemma gemma*, at a single station (37). If this population is excluded from the calculations, faunal density is actually greater in 1973 ($\bar{x}$ = 3,703 vs. 3,041 individuals/m²). Major changes in densities of individual species included decreases in *Ensis* and *Spisula* and increases in *Tellina* and the polychaete *Spiophanes bombyx*.

A third faunal group (Table 6), occurring at 21 stations (Fig. 40) with faunal similarity ≥41%, was transitional between the extremes of shallow sandy and deep muddy habitats. This group contained *Ensis directus, Tellina agilis, Ampharete arctica, Ampelisca vadorum,* and *Unciola irrorata* from the sand assemblage. Also common were *Polydora ligni, Pherusa affinis,* and *Ampelisca abdita* from the mud group, and the ubiquitous *Nassarius trivittatus* and *Oxyurostylis smithi.* The overlap between the three assemblages indicates that distributions of LIS macrofauna represent a faunal continuum rather than discrete, well-defined communities.

Populations in transitional sediments underwent faunal decline between 1972 and 1973 (Table 6) which was nearly as severe as that seen in the mud assemblage. Mean number of individuals dropped from 14,037 to 2,362/m²; much of the decrease was due to a large reduction in densities of four polychaetes, *Polydora, Amp rete, Streblospio benedicti,* and *Tharyx acutus,* and t lesser extent the bivalves *Ensis* and *Tellina.* M number of species was also substantially reduced, fall from 34.3 to 23.8 per sample. Diversity and equitabi increased due to the lowered polychaete dominan Only one species, the amphipod *Ampelisca abd* showed a major population increase.

While the "population crash" between 1972 and 1 has also been reported elsewhere for portions of LIS (M Call, 1977; Rhoads and Michael[3]), no obvious cause the decline have been uncovered. Rhoads and Mich theorized that a major erosion event in the spring of 1 may have led to widespread recruitment failure. We continuing to explore possible causes of the decline, longer term fluctuations in the mud-bottom ass blage. Frequency, severity, and causes of these fluct tions in the benthic macrofauna must be better un stood if the fauna are to be of value in environme monitoring and impact assessment. Moreover, fut management of resource finfish and crustaceans quires a thorough understanding of changes in ben populations which serve as forage for these species.

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[3] Rhoads, D. C., and A. Michael. 1974. Summary of benthic logic sampling in central Long Island Sound and New Haven Ha prior to dredging and dumping, July 1972-August 1973. Unpubl. ma scr., 15 p. Report to U.S. Corps of Engineers, by Yale University

Table 5.—Average densities/m² ($\bar{x}$), coefficients of variation (CV), and frequencies of occurrence (F) of species commonly found in shallow sandy sediments in Long Island Sound, 1972-73.

	Summer 1972			September 1973		
	n=12 stations			n=9		
	$\bar{x}$	CV,%	F,%	$\bar{x}$	CV,%	F,%
POLYCHAETES						
Nephtys picta	75	98	83	48	92	67
Aricidea catherinae	45	194	50	6	180	33
Spiophanes bombyx	25	133	67	207	113	78
Ampharete arctica	28	159	50	33	178	44
Owenia fusiformis	6	200	33	22	125	56
GASTROPODS						
Crepidula fornicata	214	253	67	96	195	44
Nassarius trivittatus	72	81	92	88	58	100
PELECYPODS						
Tellina agilis	445	170	100	1,910	206	100
Ensis directus	122	130	100	74	155	78
Spisula solidissima	795	194	75	29	167	44
Pandora gouldiana	92	150	58	32	105	67
CRUSTACEANS						
Oxyurostylis smithi	38	136	58	32	93	67
Ampelisca vadorum	92	188	67	49	212	56
Unicola irrorata	34	178	67	18	156	33
Paraphoxus epistomus	52	159	75	89	172	44
Pagurus longicarpus	37	108	83	20	90	78
Crangon septemspinosa	5	200	25	16	107	67
Total individuals/m²	6,938	189		3,703	135	
[1]Total species	23.1	48		22.9	40	
Species diversity, H'	1.92	39		1.93	29	
Equitability, J'	0.62	35		0.64	25	

[1] Means for entire samples, including rarer species.

Table 6.—Average densities/m² ($\bar{x}$), coefficients of variation (CV), and frequencies of occurrence (F) of species commonly found in "transitional" sediments in Long Island Sound, 1972-73.

	Summer 1972			September 1973		
	n=21 stations			n=13		
	$\bar{x}$	CV,%	F,%	$\bar{x}$	CV,%	F,%
POLYCHAETES						
Pectinaria gouldii	9	215	33	24	173	54
Eumida sanguinea	26	144	67	40	168	39
Glycera americana	21	115	71	45	121	69
Mediomastus ambiseta	175	159	71	143	257	46
Polydora ligni	7,131	187	95	1	360	8
Streblospio benedicti	1,549	138	86	14	160	54
Tharyx acutus	533	204	86	4	169	31
Ampharete arctica	415	185	90	43	178	62
Pherusa affinis	16	157	57	2	360	8
Nereis succinea	33	201	38	19	135	62
Spiophanes bombyx	9	244	24	38	118	54
GASTROPODS						
Nassarius trivittatus	91	81	95	109	89	92
PELECYPODS						
Tellina agilis	418	109	86	222	110	69
Ensis directus	281	96	100	104	119	62
CRUSTACEANS						
Oxyurostylis smithi	52	185	62	3	205	23
Ampelisca abdita	96	194	76	44	278	31
Ampelisca vadorum	81	222	57	508	260	85
Unicola irrorata	48	120	81	15	230	31
Crangon septemspinosa	18	150	48	22	93	85
Pagurus longicarpus	16	253	43	19	139	54
ASTEROIDS						
Asterias forbesi	46	273	48	32	163	69
[1]Total individuals/m²	14,037	118		2,362	62	
[1]Total species	34.3	27		23.8	52	
[1]Species diversity, H'	1.83	27		2.03	12	
[1]Equitability, J'	0.53	28		0.64	10	

[1] Means for entire samples, including rarer species.

ACKNOWLEDGMENTS

uth Turner and Austin Williams aided in identification of molluscs and decapods, respectively. Errors in identification or nomenclature, however, remain our responsibility. Illustration work was done by Michele Cox typing by Diane McDonnell. John Pearce reviewed the report and made helpful suggestions. We also wish to thank the many persons who served as crew and scientists on field surveys and who carried out the bulk of sorting, identifying, and enumerating of benthic macrofauna.

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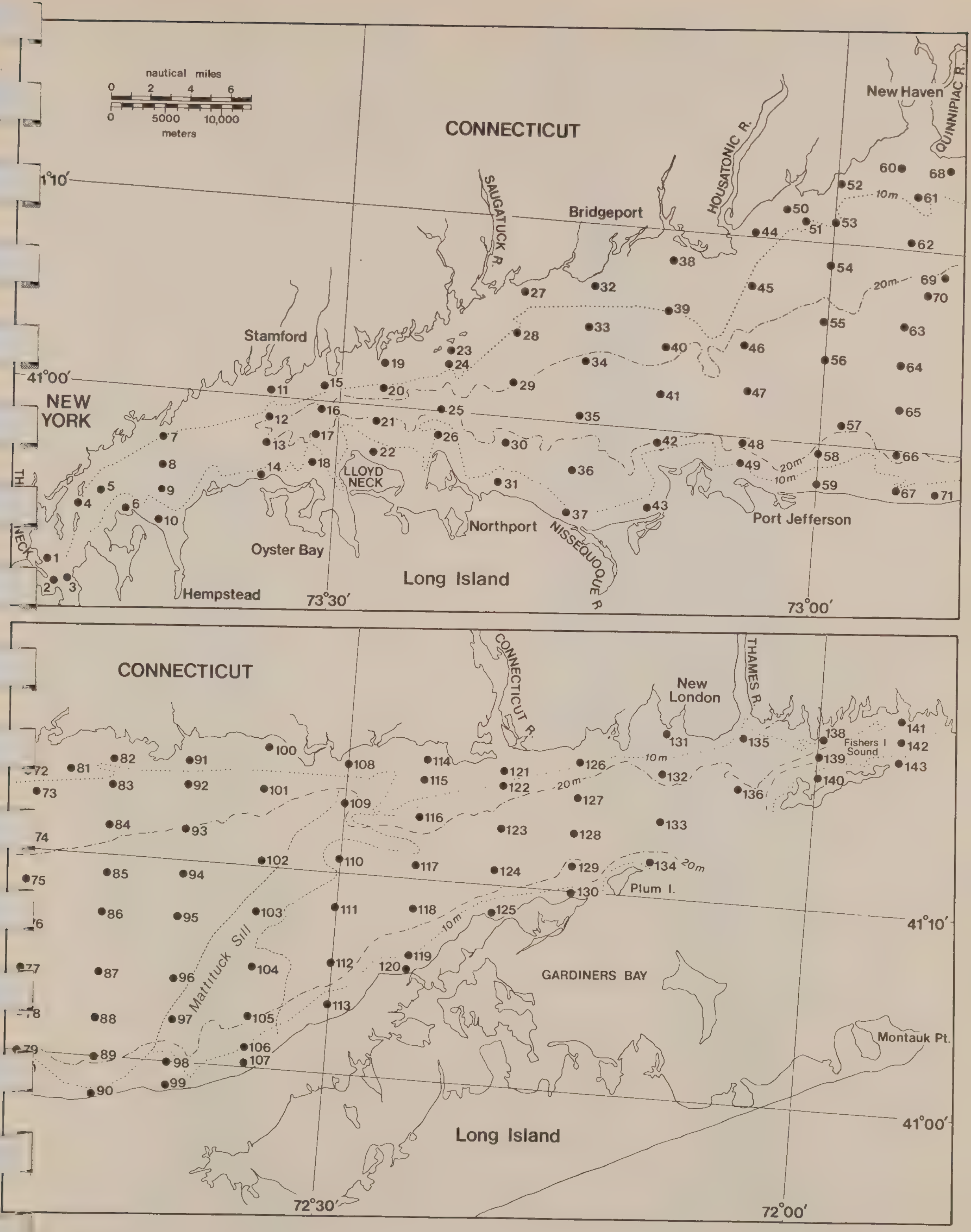
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Figure 1.—Sampling pattern in Long Island Sound.

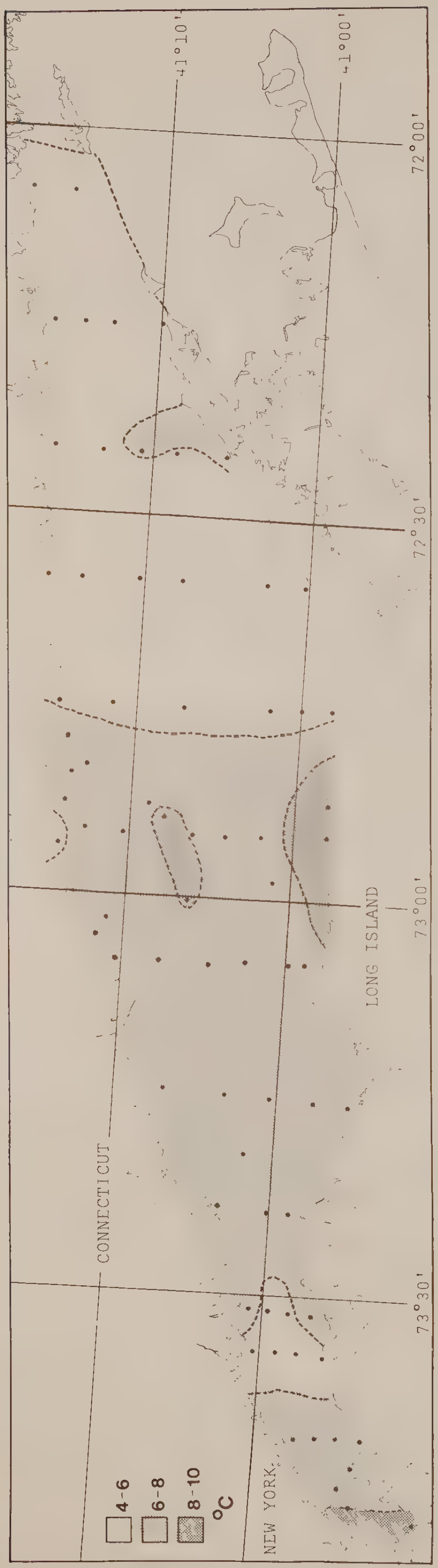

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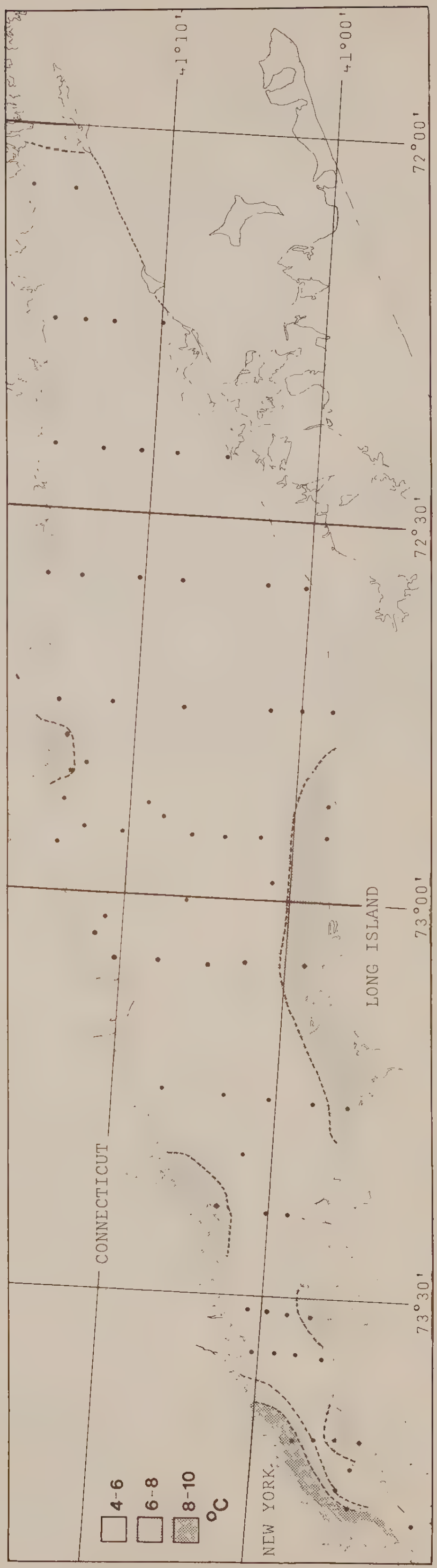
Figure 2.—Surface temperature, Long Island Sound, April 1973.



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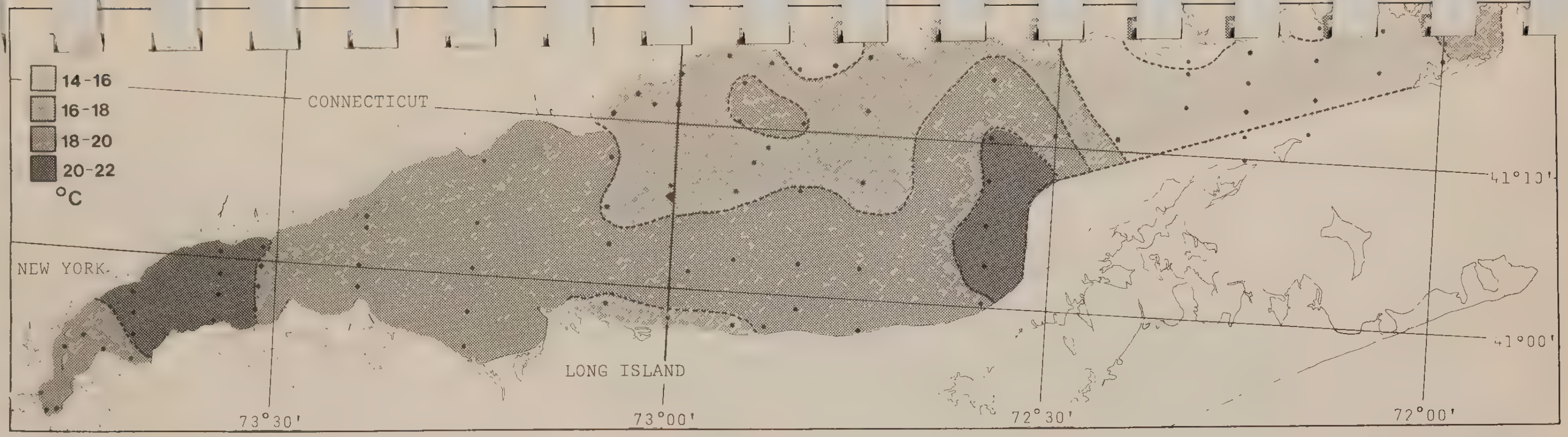
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Figure 4.—Surface temperature, Long Island Sound, September 1973.

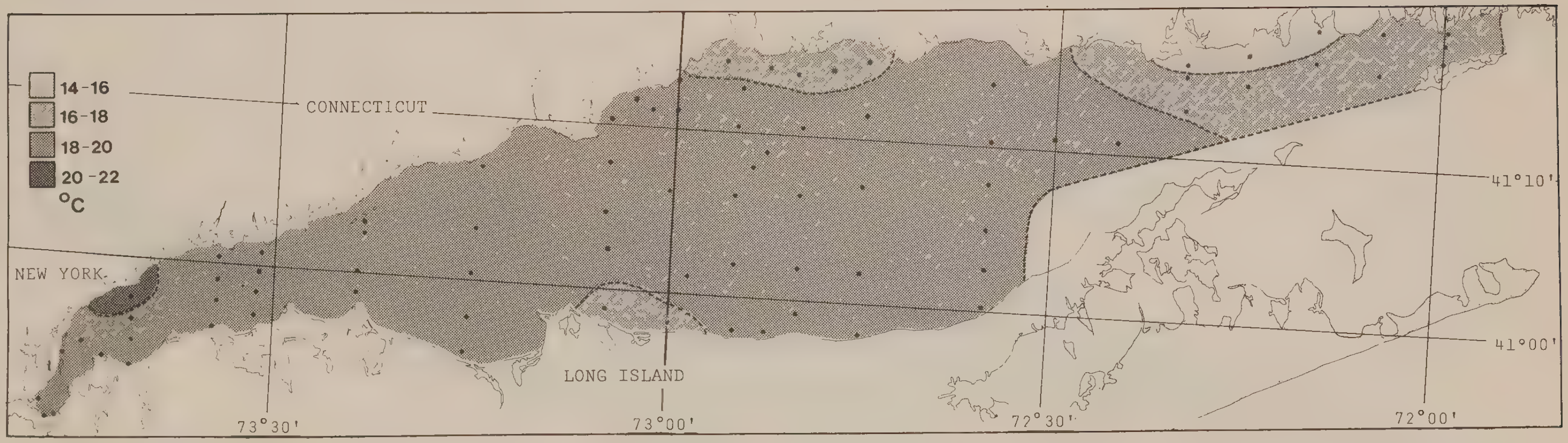
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Figure 5.—Bottom temperature, Long Island Sound, September 1973.

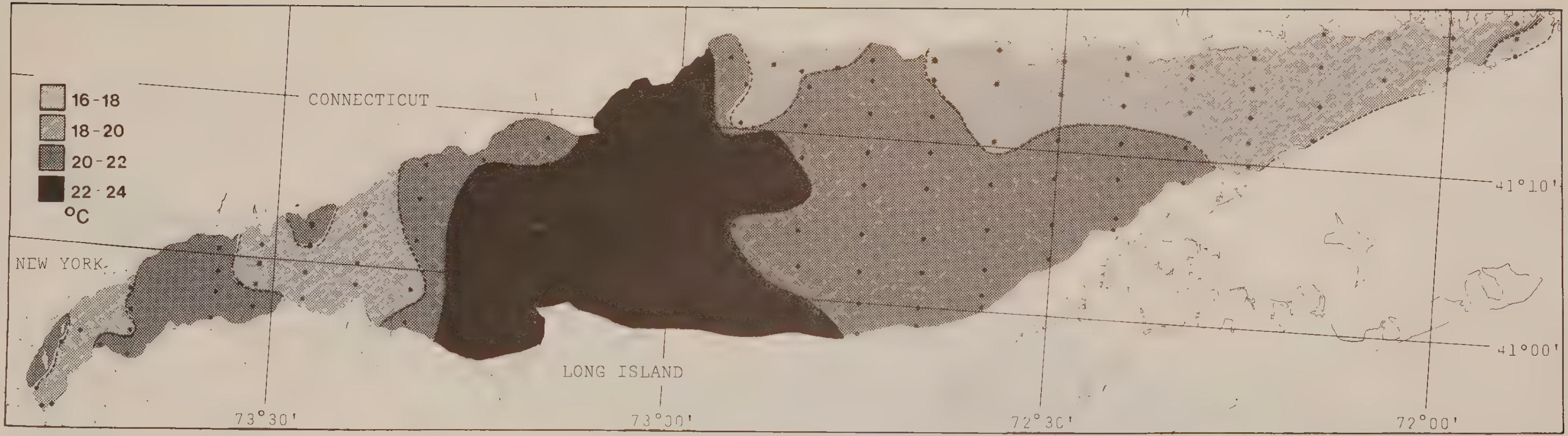
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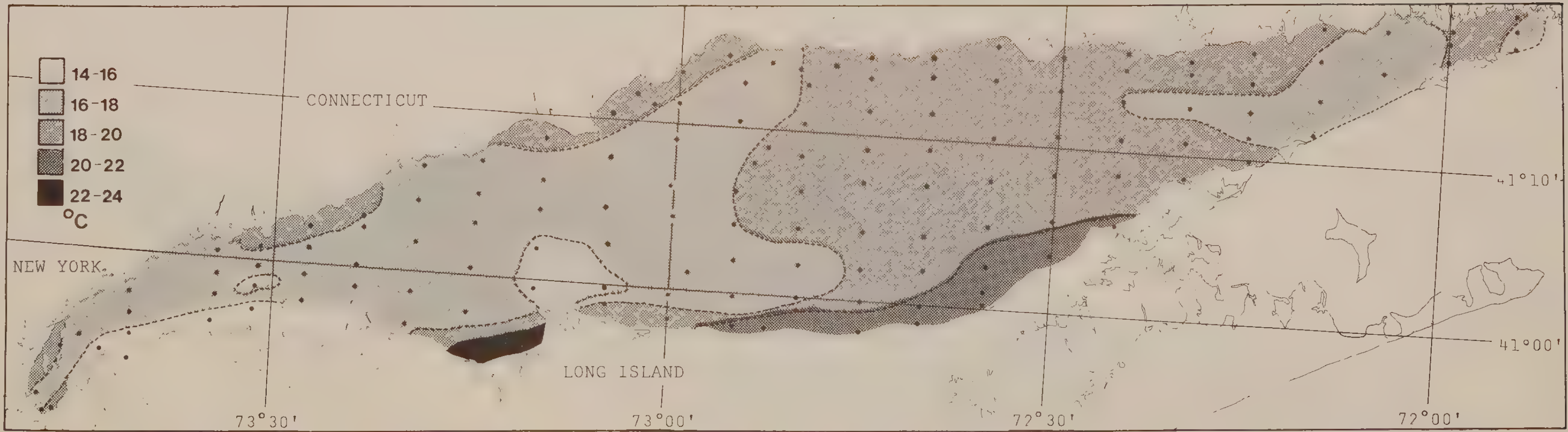
Figure 6.—Surface temperature, Long Island Sound, summer 1972.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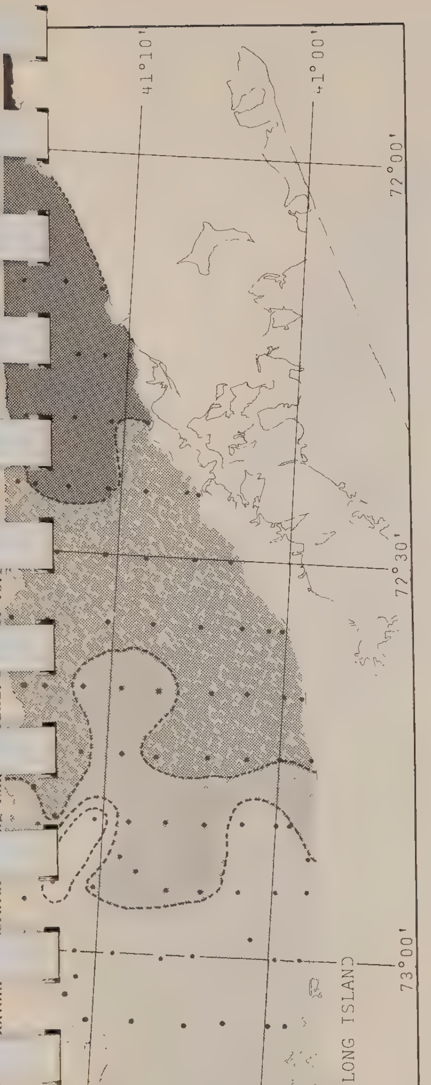
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Figure 8.—Surface salinity, Long Island Sound, summer 1972.

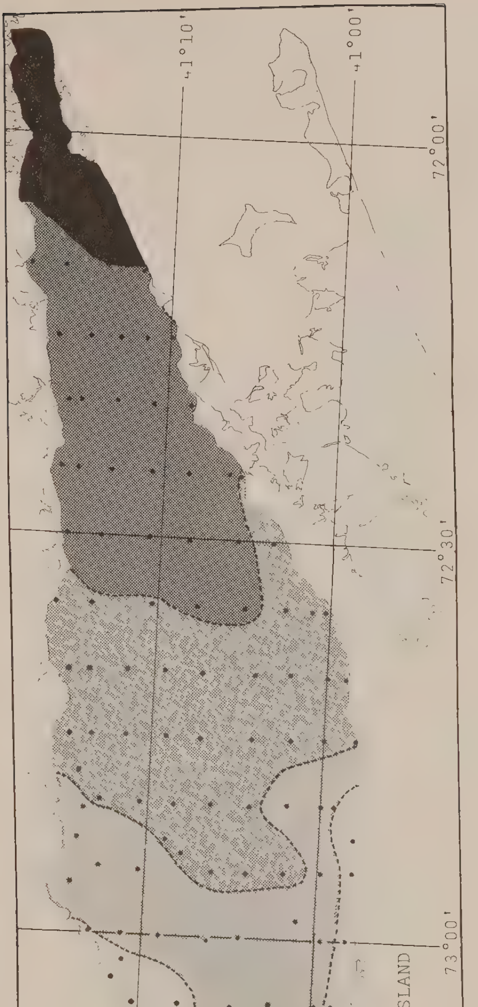
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Figure 9.—Bottom salinity, Long Island Sound, summer 1972.

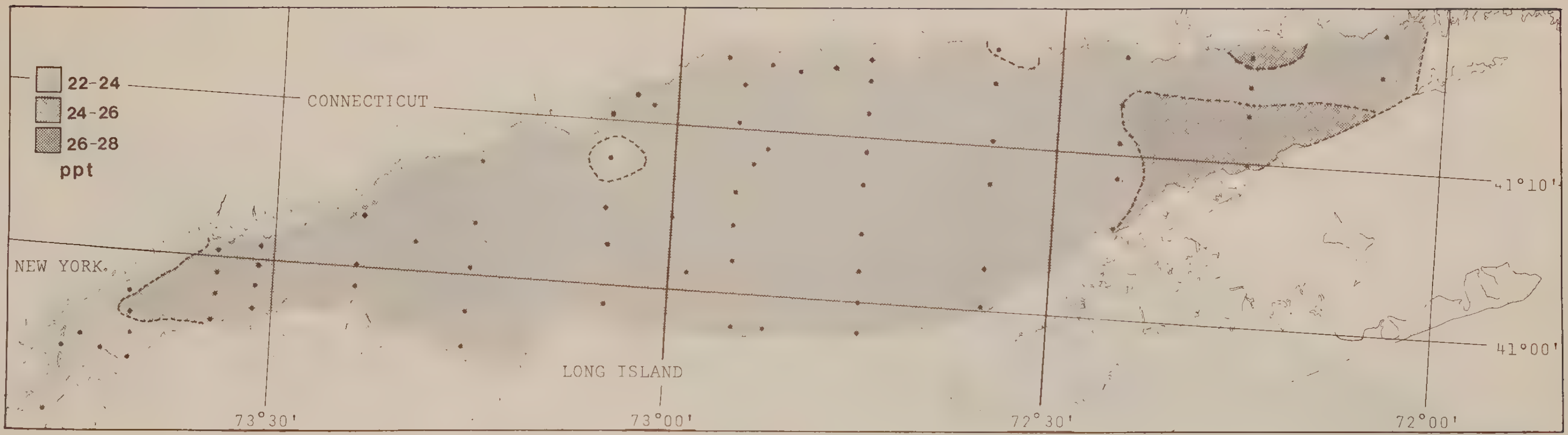
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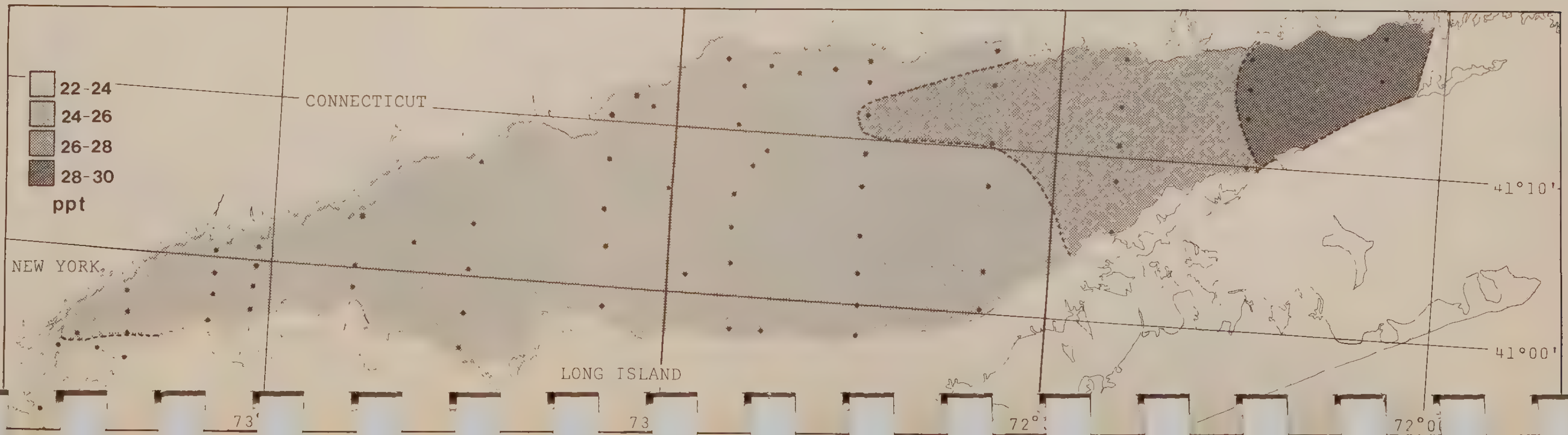
Figure 10.—Surface salinity, Long Island Sound, April 1973.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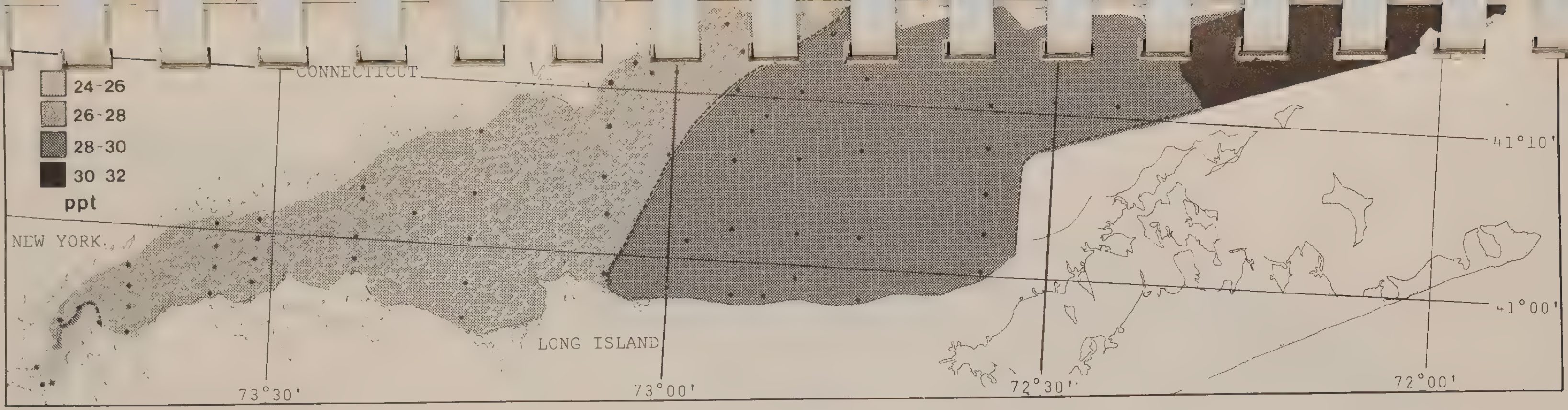
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Figure 12.—Surface salinity, Long Island Sound, September 1973.

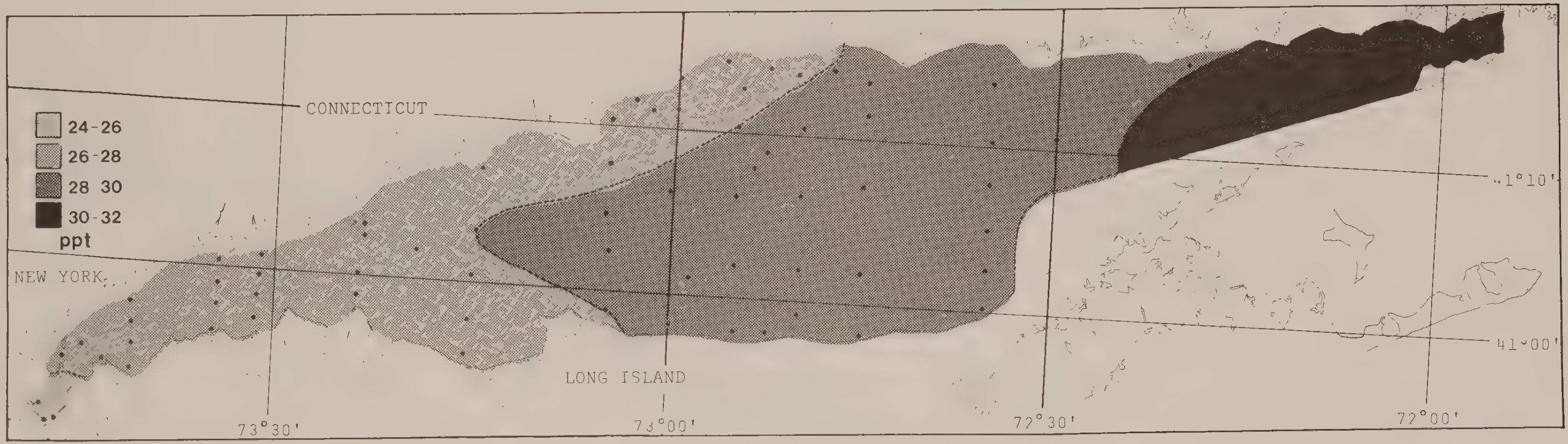
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Figure 13.—Bottom salinity, Long Island Sound, September 1973.

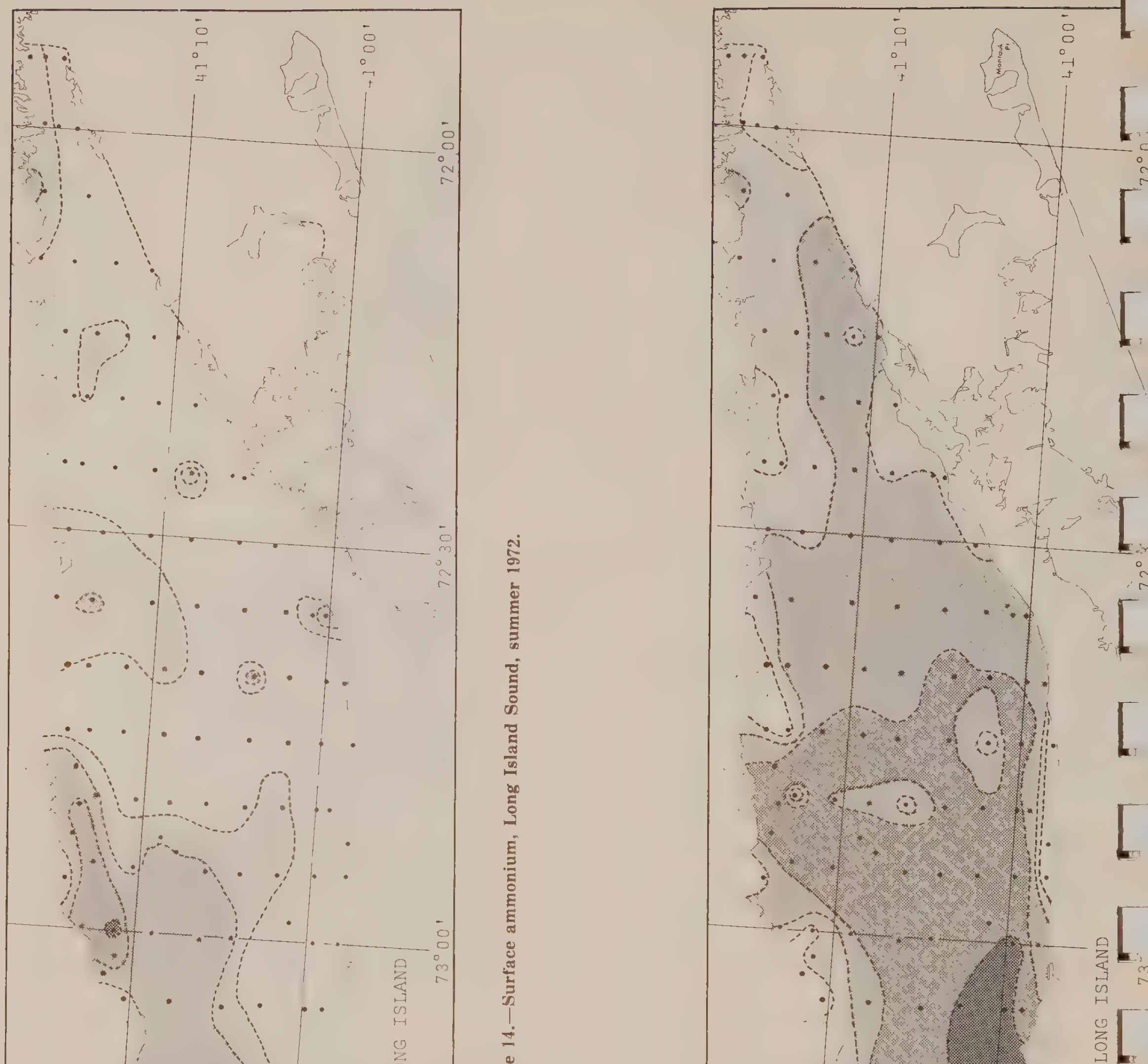

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Figure 14.—Surface ammonium, Long Island Sound, summer 1972.

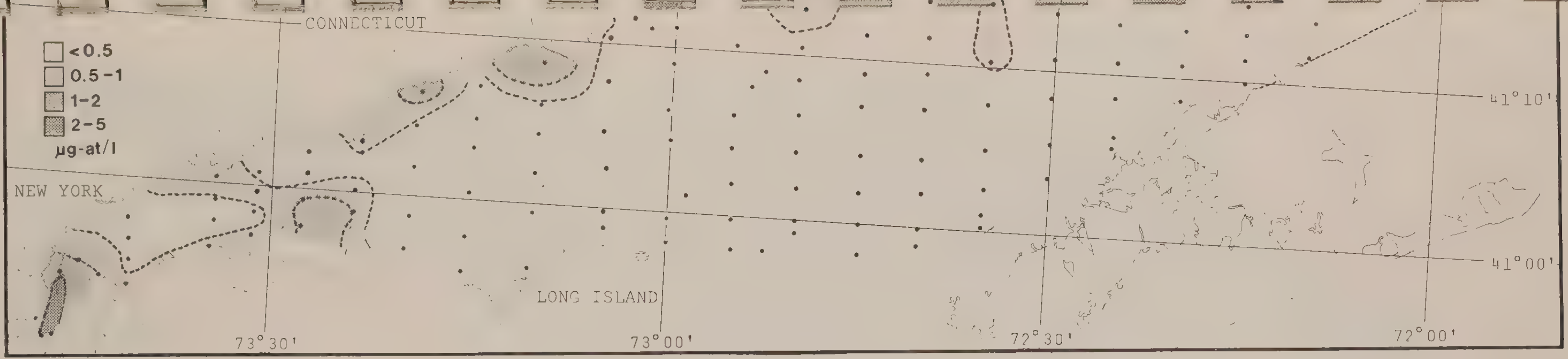
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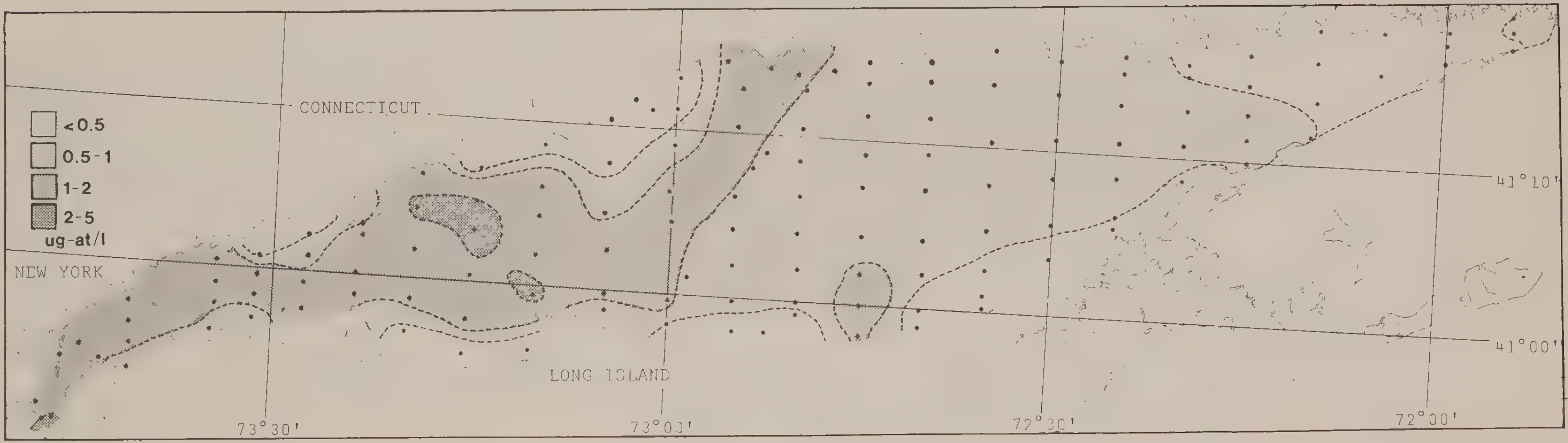
Figure 16.—Surface nitrate, Long Island Sound, summer 1972.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72°00'

Figure 17.—Bottom nitrate, Long Island Sound, summer 1972.

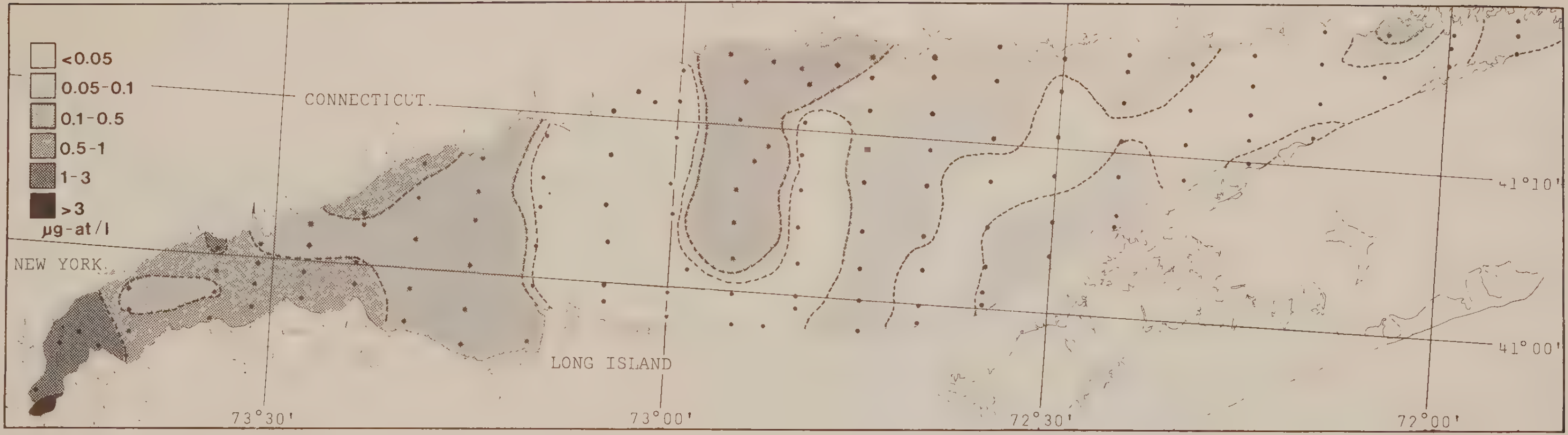
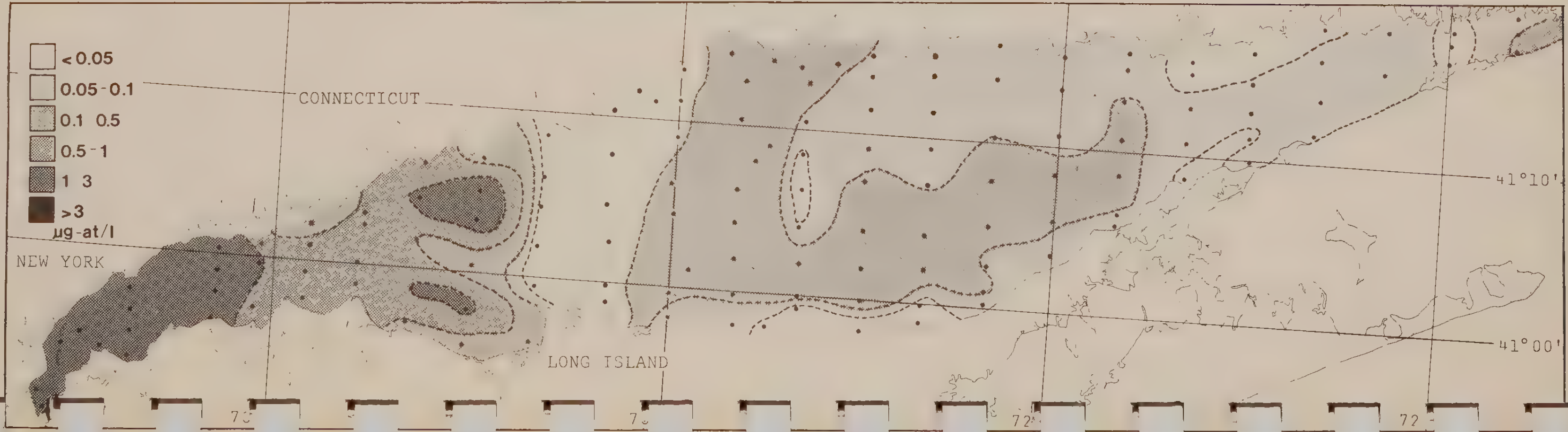

<0.05
0.05-0.1
0.1-0.5
0.5-1
1-3
>3
µg-at/l
CONNECTICUT
NEW YORK
LONG ISLAND
41°10'
41°00'
73°30'
73°00'
72°30'
72°00'

Figure 18.—Surface nitrite, Long Island Sound, summer 1972.


<0.05
0.05-0.1
0.1 0.5
0.5-1
1 3
>3
µg-at/l
CONNECTICUT
NEW YORK
LONG ISLAND
41°10'
41°00'

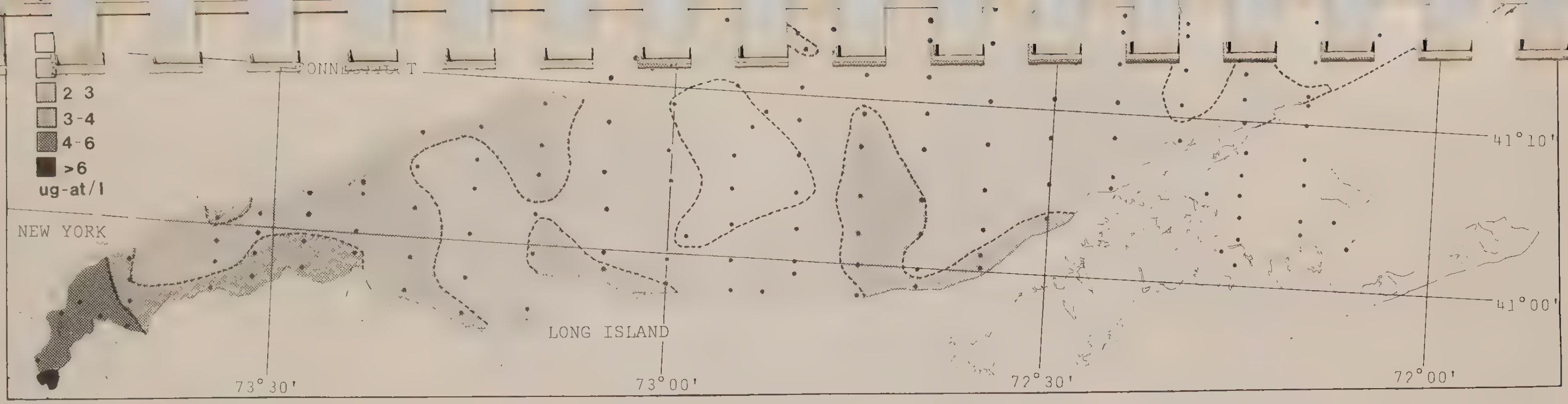

2 3
3-4
4-6
>6
ug-at/l
CONNECTICUT
NEW YORK
LONG ISLAND
41°10'
41°00'
73°30'
73°00'
72°30'
72°00'

Figure 20.—Surface orthophosphorus, Long Island Sound, summer 1972.

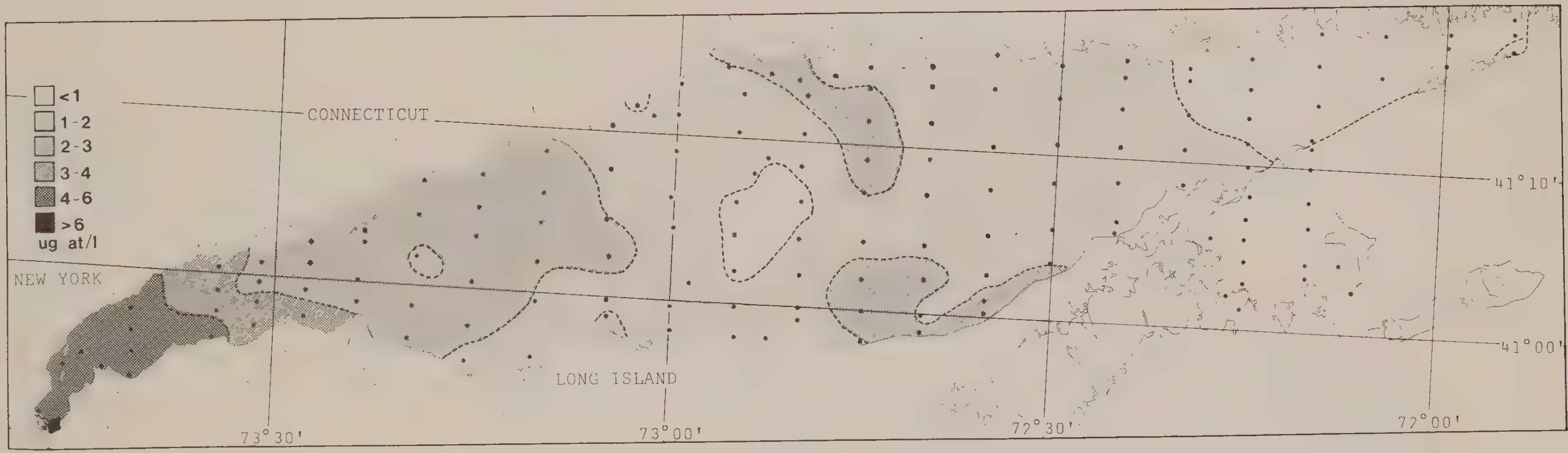

<1
1-2
2-3
3-4
4-6
>6
ug at/l
CONNECTICUT
NEW YORK
LONG ISLAND
41°10'
41°00'
73°30'
73°00'
72°30'
72°00'

Figure 21.—Bottom orthophosphorus, Long Island Sound, summer 1972.

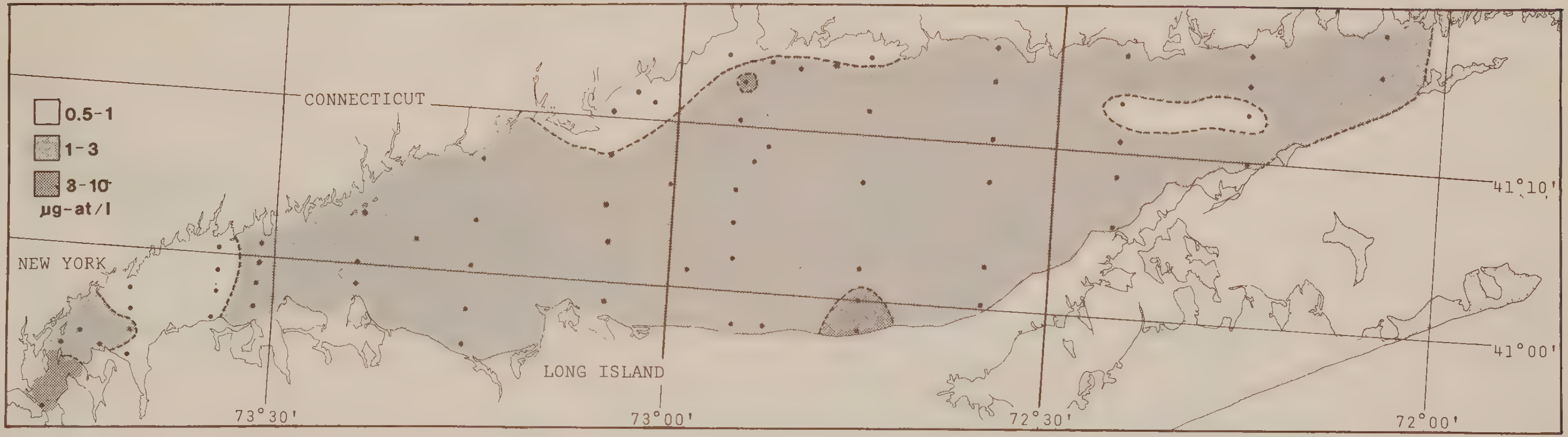
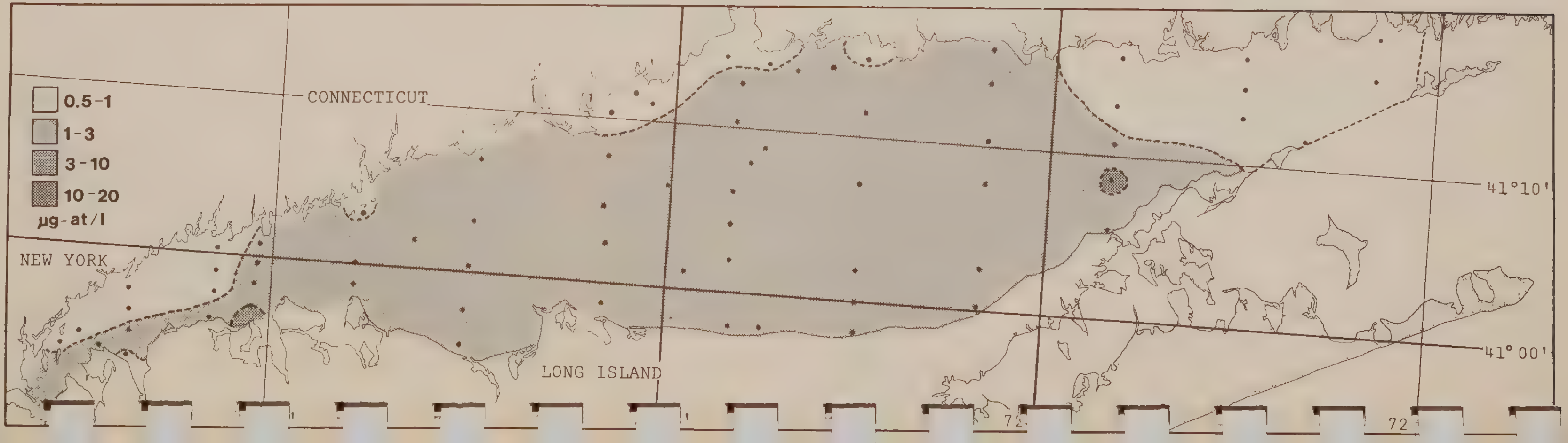

0.5-1
1-3
3-10
µg-at/l
CONNECTICUT
NEW YORK
LONG ISLAND
73°30'
73°00'
72°30'
72°00'
41°10'
41°00'

Figure 22.—Surface ammonium, Long Island Sound, April 1973.


0.5-1
1-3
3-10
10-20
µg-at/l
CONNECTICUT
NEW YORK
LONG ISLAND
41°10'
41°00'

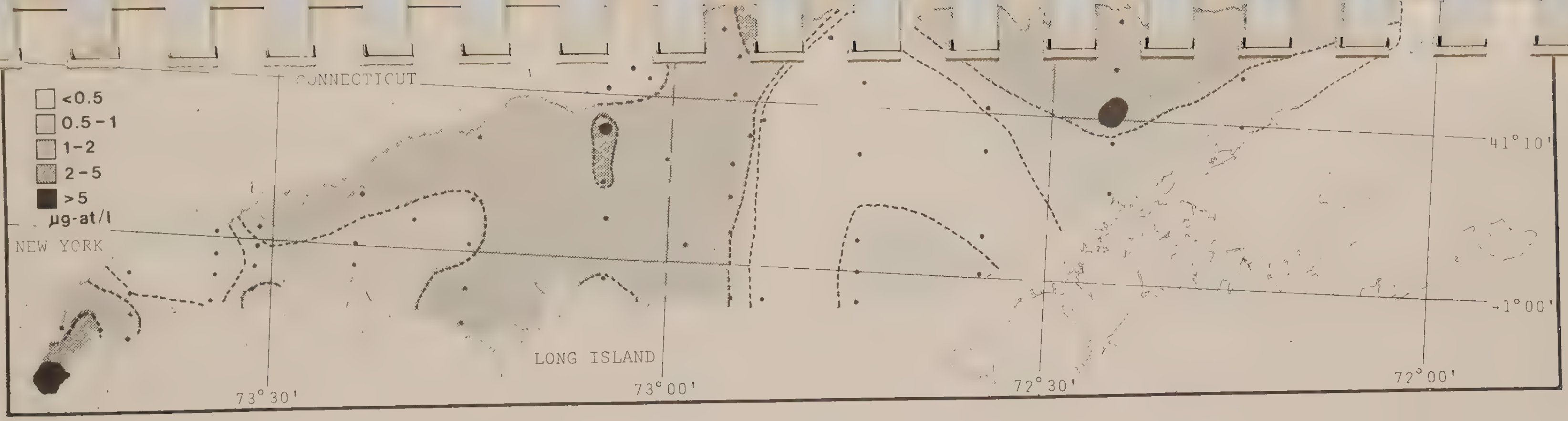

CONNECTICUT
NEW YORK
LONG ISLAND
<0.5
0.5-1
1-2
2-5
>5
µg-at/l
41°10'
41°00'
73°30'
73°00'
72°30'
72°00'

Figure 24.—Surface nitrate, Long Island Sound, April 1973.

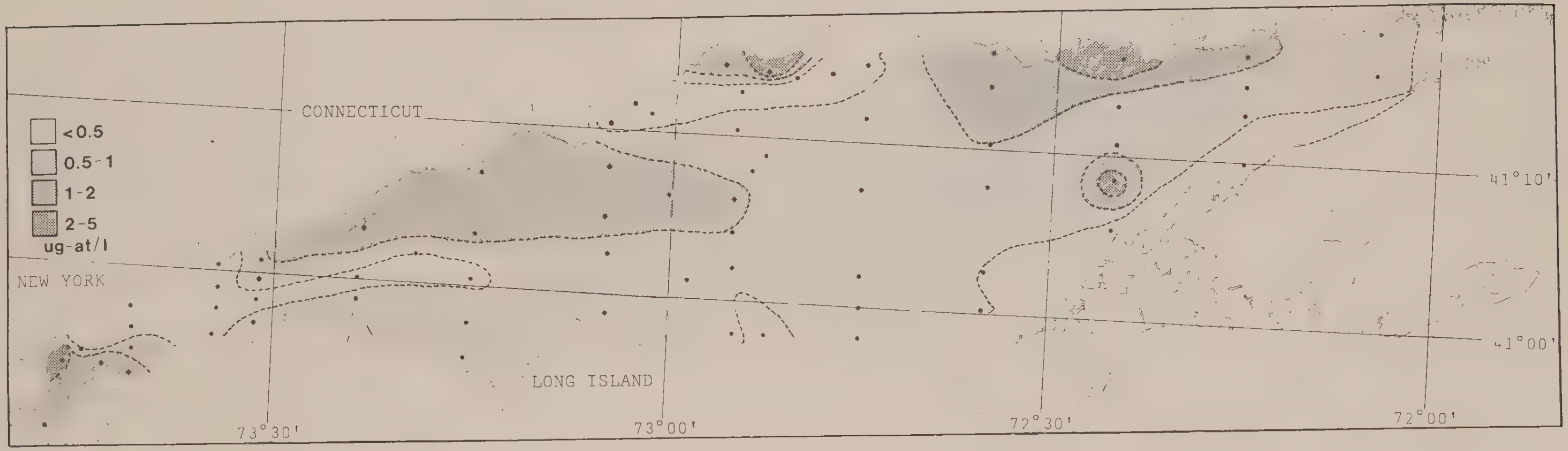

CONNECTICUT
NEW YORK
LONG ISLAND
<0.5
0.5-1
1-2
2-5
ug-at/l
41°10'
41°00'
73°30'
73°00'
72°30'
72°00'

Figure 25.—Bottom nitrate, Long Island Sound, April 1973.

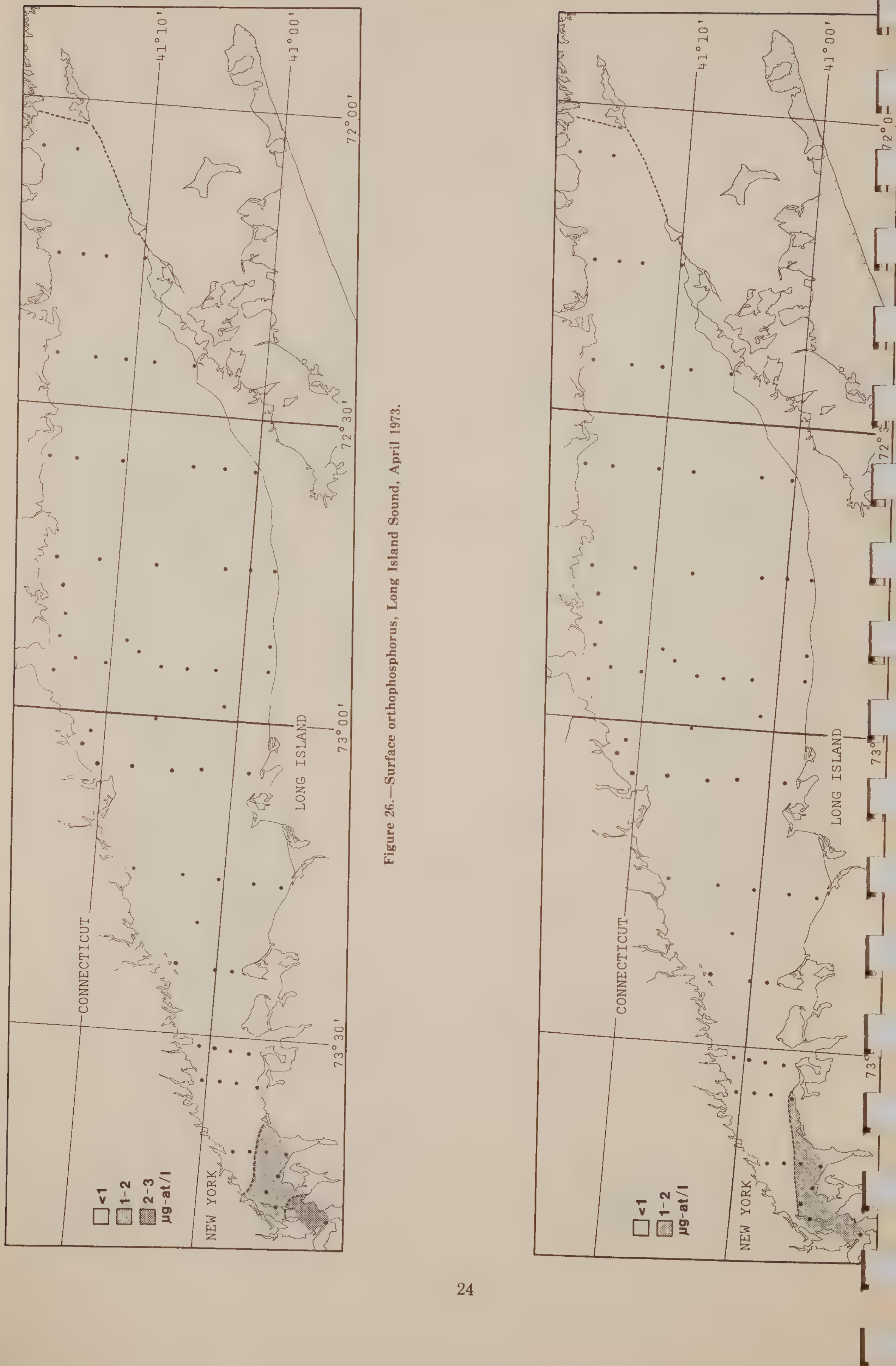

41°10'
41°00'
72°00'
72°30'
73°00'
73°30'
CONNECTICUT
NEW YORK
LONG ISLAND
<1
1-2
2-3
µg-at/l
41°10'
41°00'
72°0
72°3
73°
73°
CONNECTICUT
NEW YORK
LONG ISLAND
<1
1-2
µg-at/l

Figure 26.—Surface orthophosphorus, Long Island Sound, April 1973.

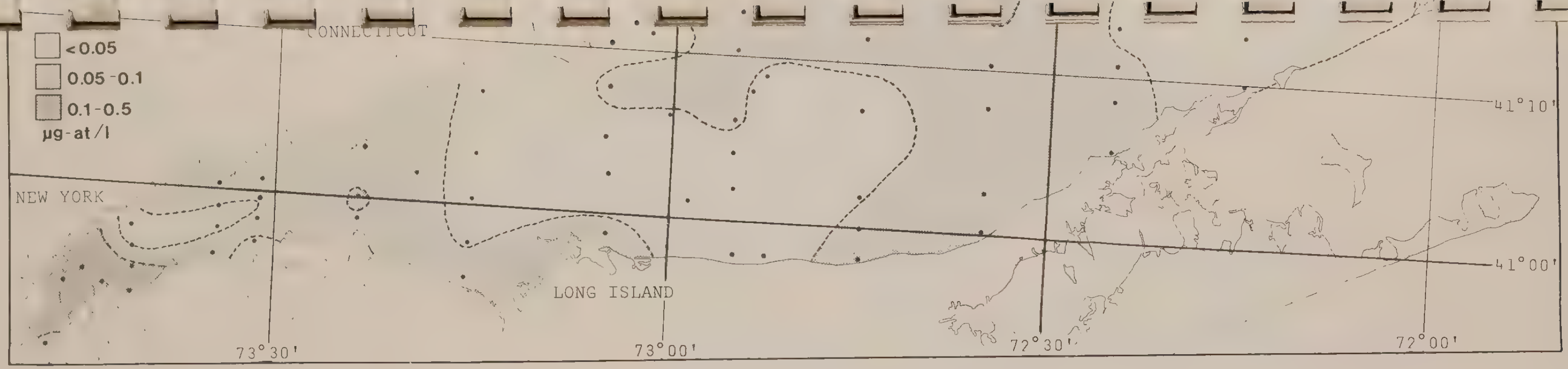

CONNECTICUT
<0.05
0.05-0.1
0.1-0.5
µg-at/l
NEW YORK
LONG ISLAND
41°10'
41°00'
73°30'
73°00'
72°30'
72°00'

Figure 28.—Surface nitrite, Long Island Sound, April 1973.

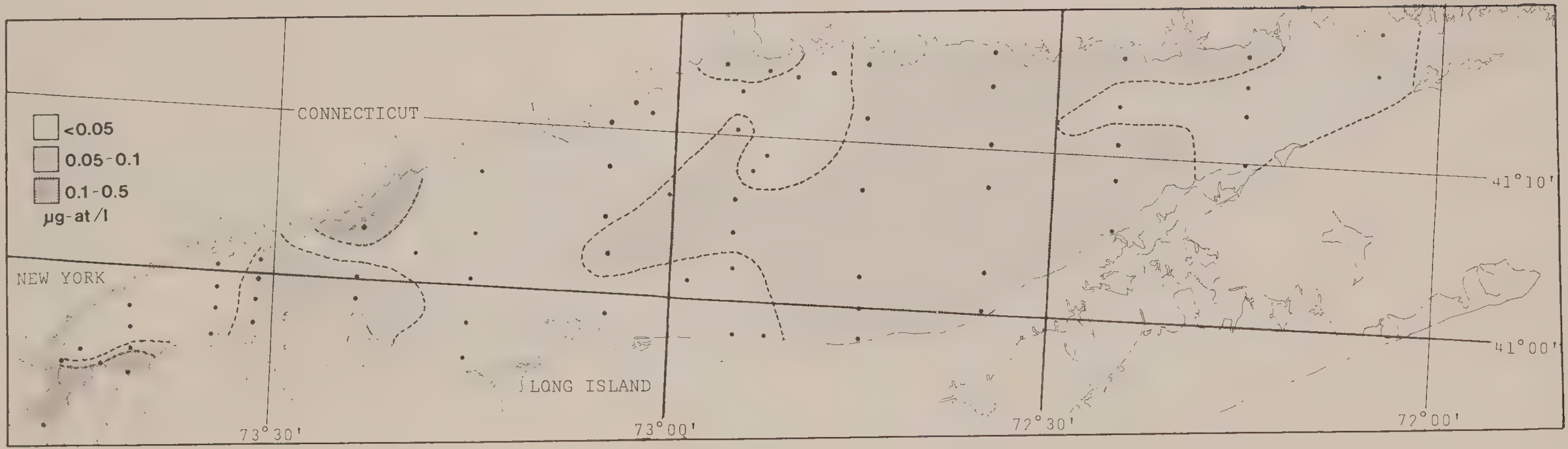

CONNECTICUT
<0.05
0.05-0.1
0.1-0.5
µg-at/l
NEW YORK
LONG ISLAND
41°10'
41°00'
73°30'
73°00'
72°30'
72°00'

Figure 29.—Bottom nitrite, Long Island Sound, April 1973.

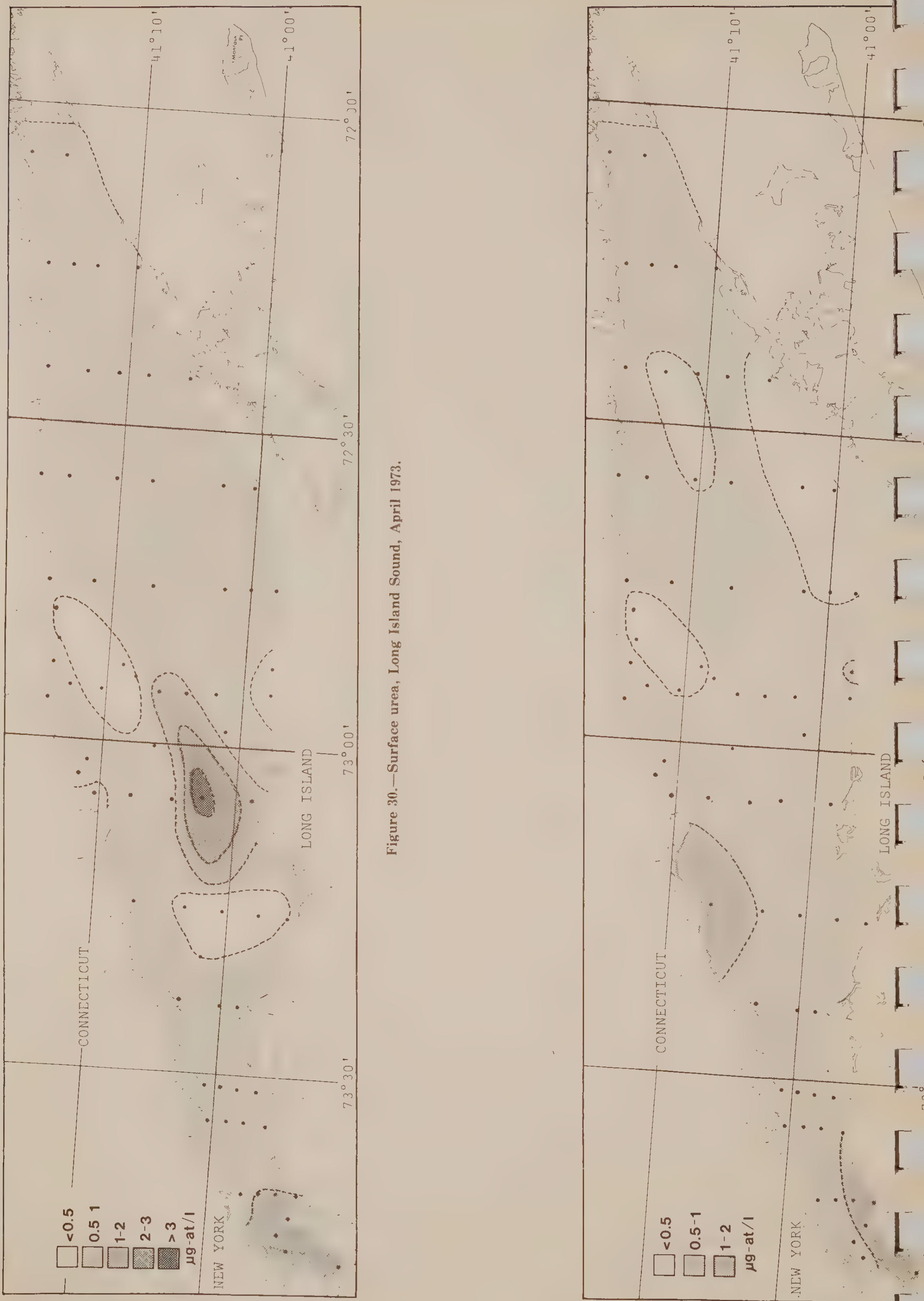

41°10'
41°00'
72°10'
72°30'
73°00'
73°30'
Montauk Pt.
CONNECTICUT
LONG ISLAND
NEW YORK
<0.5
0.5 1
1-2
2-3
>3
µg-at/l
41°10'
41°00'
CONNECTICUT
LONG ISLAND
NEW YORK
<0.5
0.5-1
1-2
µg-at/l

Figure 30.—Surface urea, Long Island Sound, April 1973.

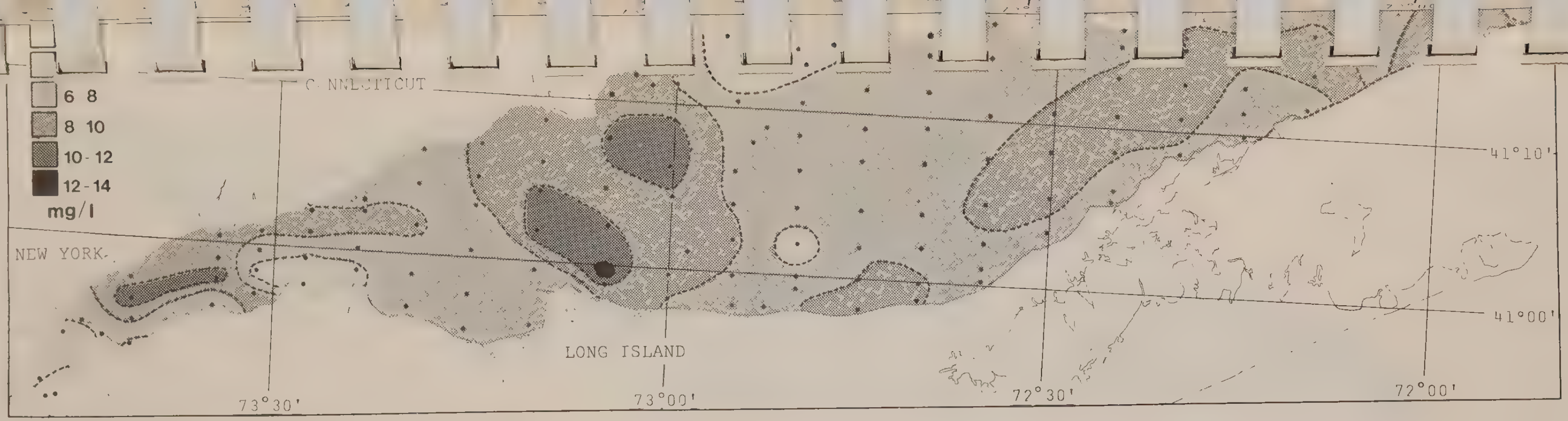

6 8
8 10
10-12
12-14
mg/l
CONNECTICUT
NEW YORK
LONG ISLAND
41°10'
41°00'
73°30'
73°00'
72°30'
72°00'

Figure 32.—Surface dissolved oxygen, Long Island Sound, summer 1972.

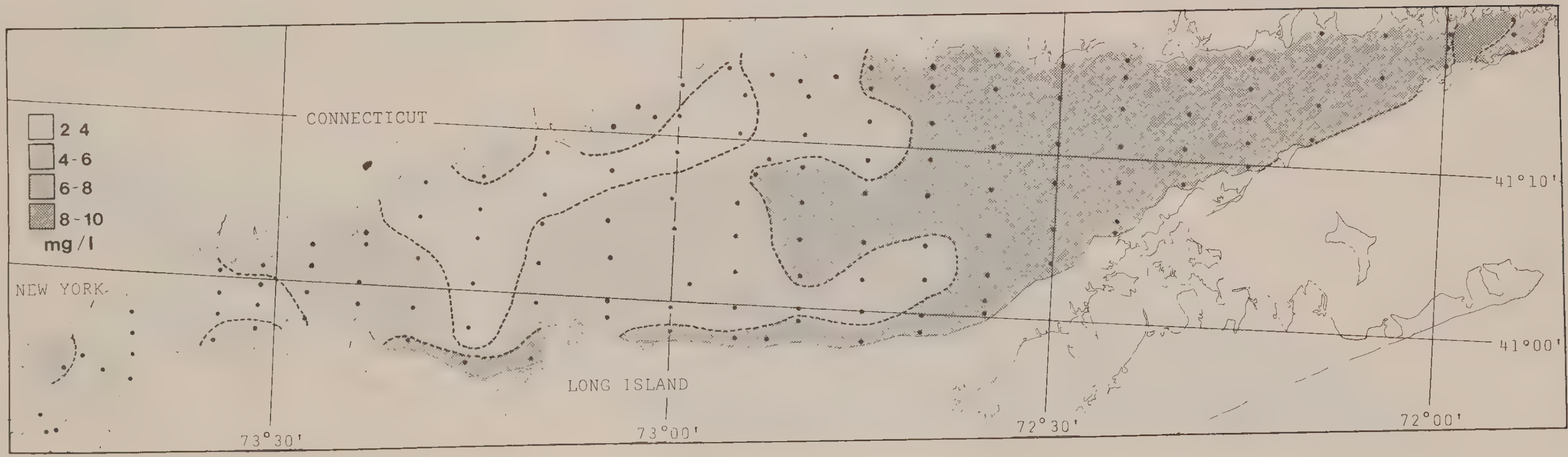

2 4
4-6
6-8
8-10
mg/l
CONNECTICUT
NEW YORK
LONG ISLAND
41°10'
41°00'
73°30'
73°00'
72°30'
72°00'

Figure 33.—Bottom dissolved oxygen, Long Island Sound, summer 1972.

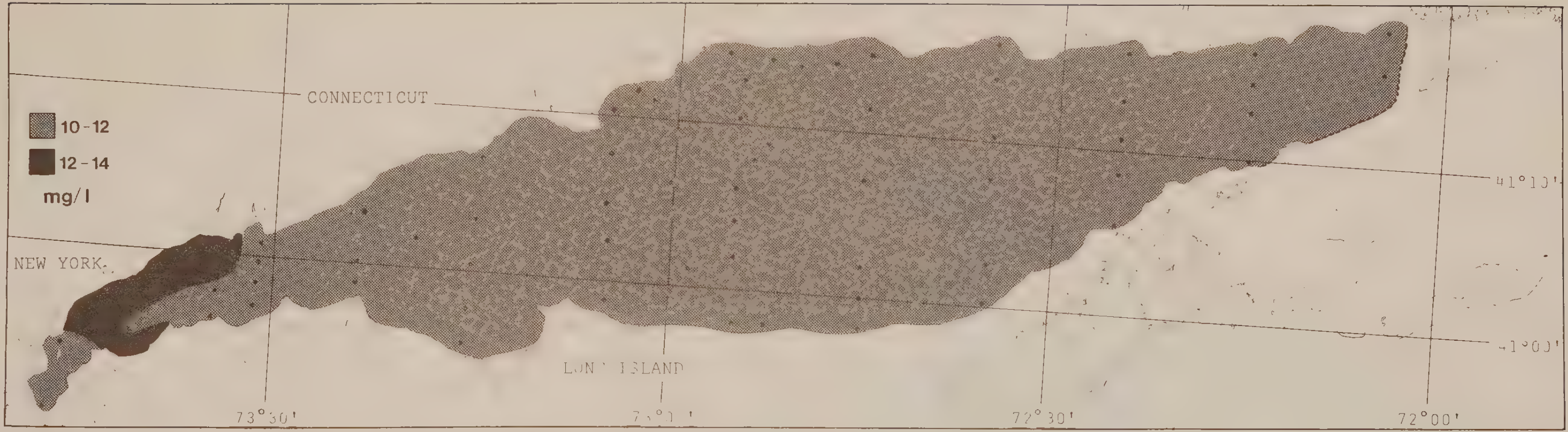
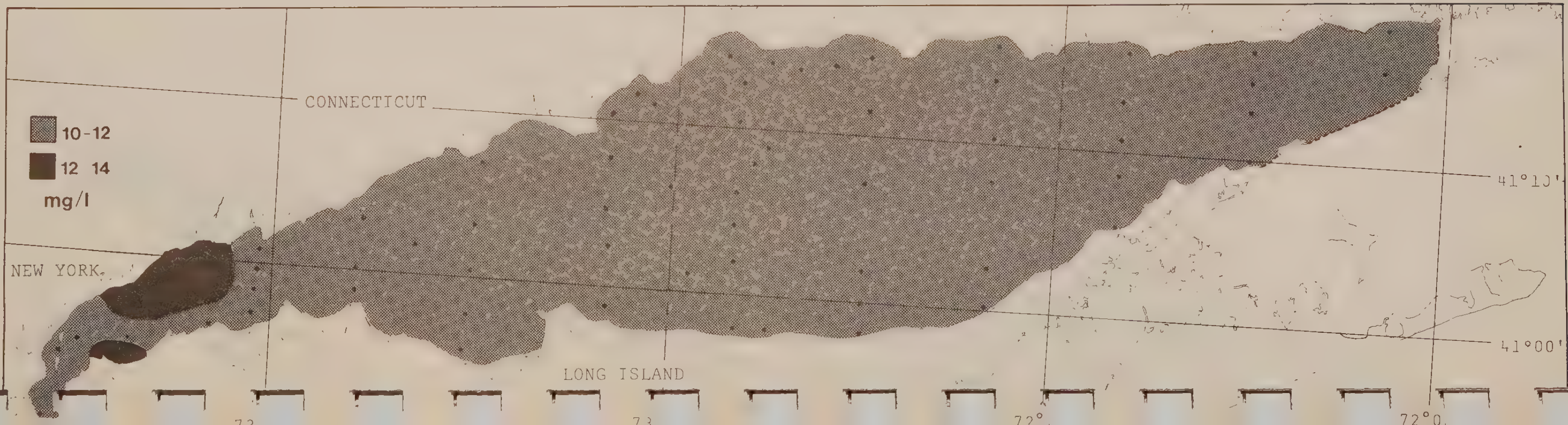

10-12
12-14
mg/l
CONNECTICUT
NEW YORK
LONG ISLAND
41°10'
41°00'
73°30'
73°00'
72°30'
72°00'

Figure 34.—Surface dissolved oxygen, Long Island Sound, April 1973.


10-12
12 14
mg/l
CONNECTICUT
NEW YORK
LONG ISLAND
41°10'
41°00'

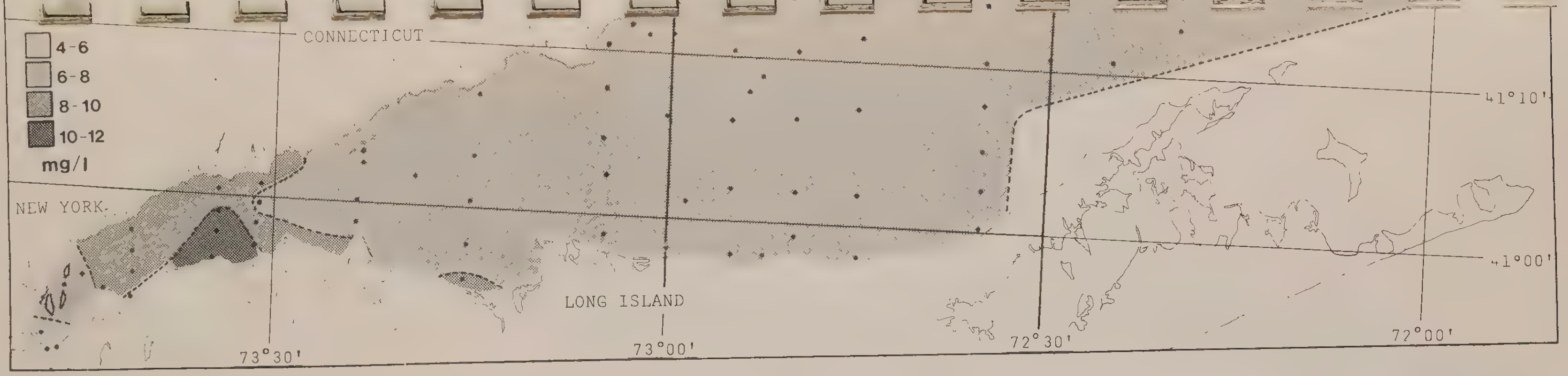

4-6
6-8
8-10
10-12
mg/l
CONNECTICUT
NEW YORK
LONG ISLAND
41°10'
41°00'
73°30'
73°00'
72°30'
72°00'

Figure 36.—Surface dissolved oxygen, Long Island Sound, September 1973.

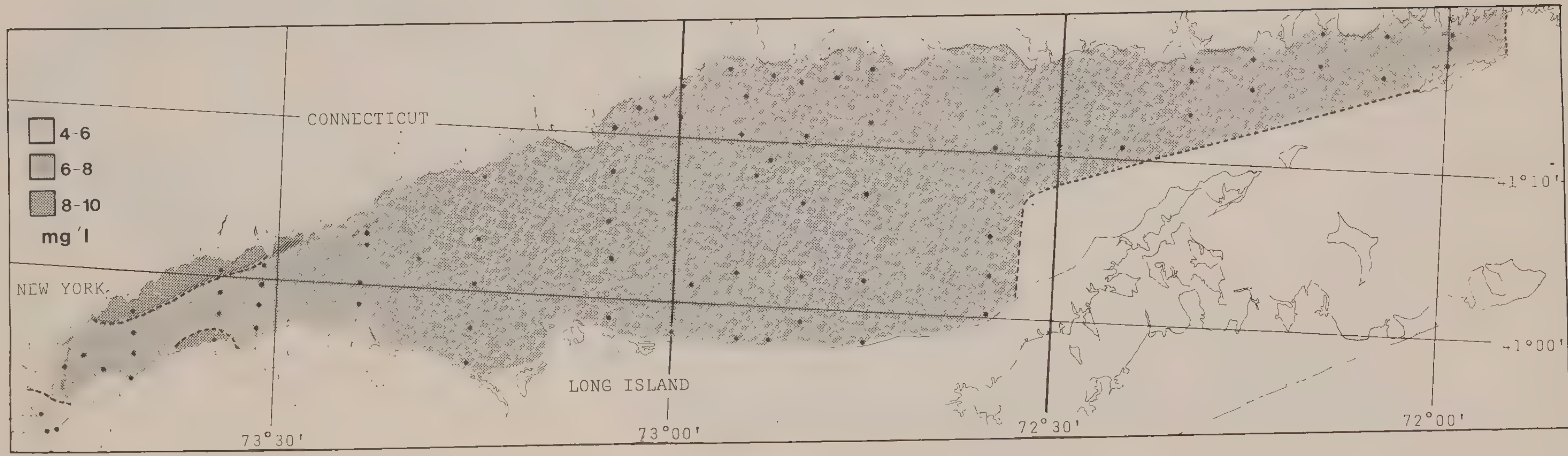

4-6
6-8
8-10
mg/l
CONNECTICUT
NEW YORK
LONG ISLAND
41°10'
41°00'
73°30'
73°00'
72°30'
72°00'

Figure 37.– Bottom dissolved oxygen, Long Island Sound, September 1973.

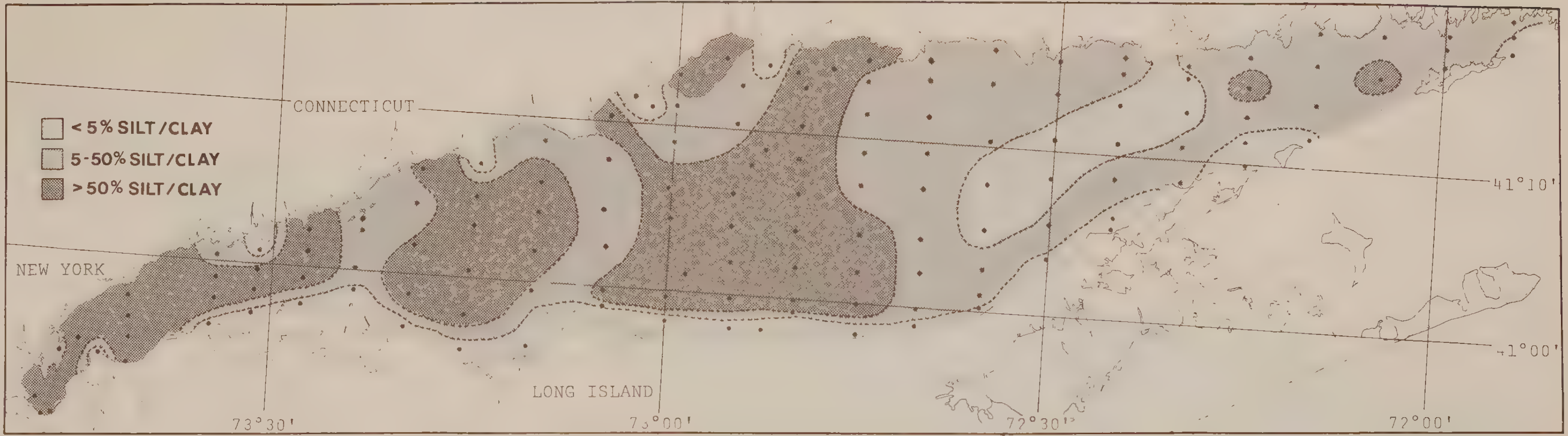
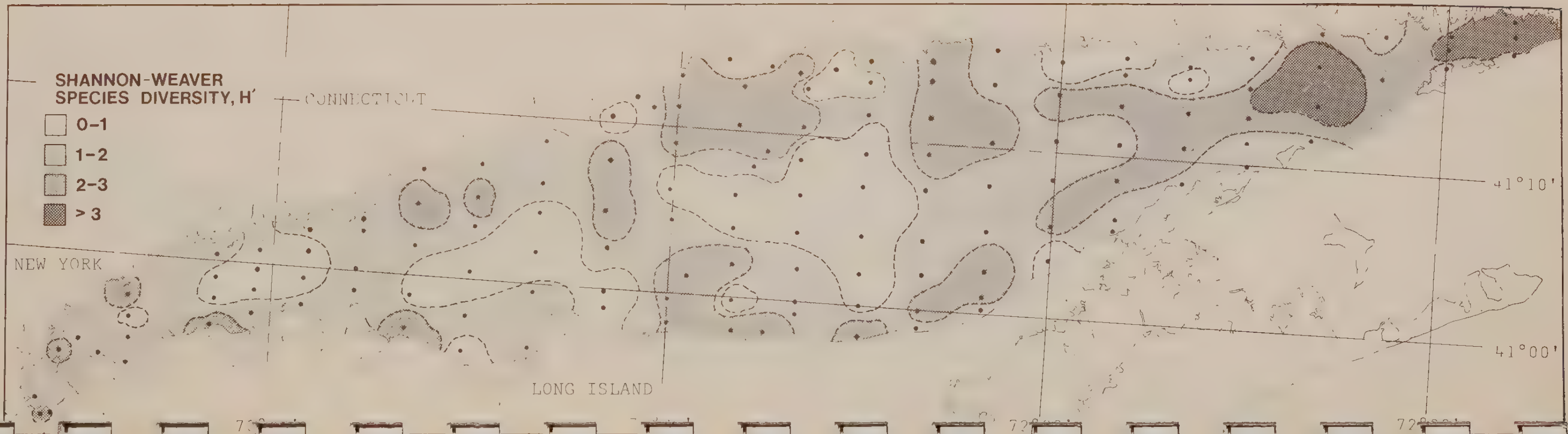

CONNECTICUT
< 5% SILT/CLAY
5-50% SILT/CLAY
> 50% SILT/CLAY
NEW YORK
LONG ISLAND
41°10'
41°00'
73°30'
73°00'
72°30'
72°00'

Figure 38.—Distribution of silts and clays (<62μm) in surface sediments, Long Island Sound, summer 1972.


SHANNON-WEAVER
SPECIES DIVERSITY, H′
0–1
1–2
2–3
> 3
CONNECTICUT
NEW YORK
LONG ISLAND
41°10'
41°00'

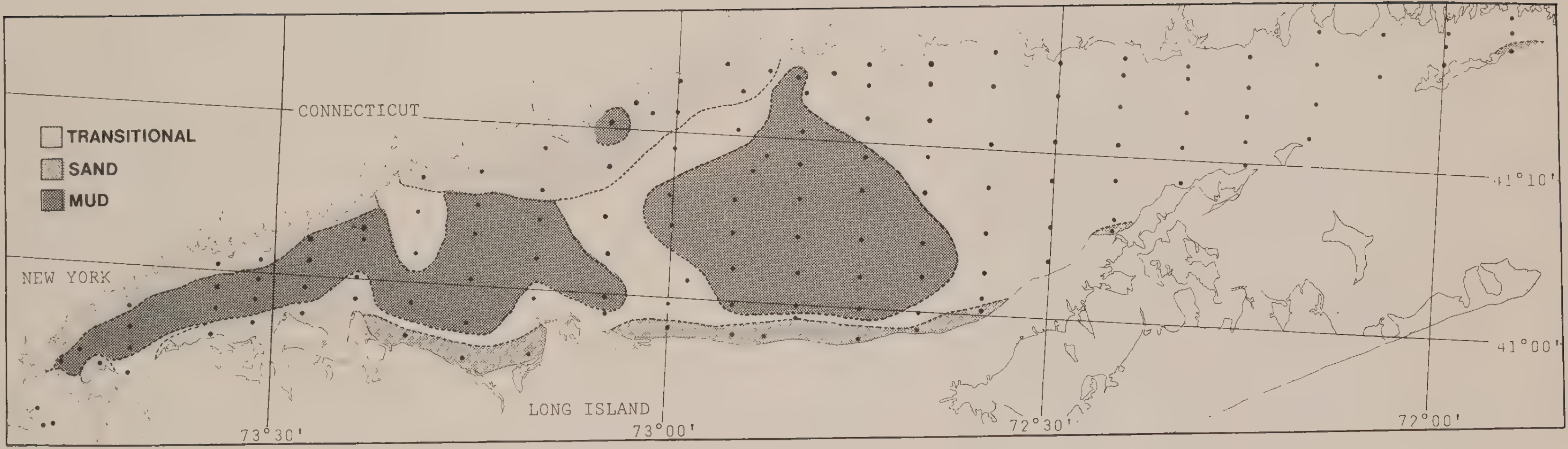

CONNECTICUT
TRANSITIONAL
SAND
MUD
NEW YORK
LONG ISLAND
41°10'
41°00'
73°30'
73°00'
72°30'
72°00'

Figure 40.—Distribution of mud, sand, and transitional faunal assemblages, Long Island Sound, summer 1972.

NOAA Technical Report NMFS SSRF-739

Bottom-Water Temperature Trends in the Middle Atlantic Bight During Spring and Autumn, 1964-76

Clarence W. Davis

December 1979

U.S. DEPARTMENT OF COMMERCE
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Bottom-Water Temperature Trends in the Middle Atlantic Bight During Spring and Autumn, 1964-76

CLARENCE W. DAVIS[1]

ABSTRACT

Annual variations of bottom-water temperatures on the continental shelf between Cape Cod and Cape Hatteras were examined for the spring and autumn from 1964 to 1976. Temperatures generally were highest since 1972 during both seasons. For waters between Cape Cod and Hudson Canyon, maximum temperatures occurred in the spring of 1976 (8.3°C) and autumn of 1972 (12.8°); between Cape Hatteras and Hudson Canyon, temperatures peaked in the spring of 1974 (9.0°C) and the autumn of 1972 (15.7°C). Minimum temperatures were in the spring of 1970 (5.1°C) and autumn of 1967 (9.7°C) and in the spring (4.6°C) and autumn (12.1°C) of 1970 in the respective areas.

Some factors that affect bottom-water temperatures, the relationship of the observed temperature variations to temperature fluctuations in other areas of the northwest Atlantic, and the effects of temperature changes on the distribution of several fish species are briefly discussed.

INTRODUCTION

he purpose of this study was to examine bottom-water temperature data collected since 1964 in the area between Cape Cod, Mass., and Cape Hatteras, N.C., to reveal annual variations and any possible warming or ing trends that may have occurred. Since bottom-water temperatures are less affected by localized and short-term atmospheric phenomena than sea-surface temperatures, they can be linked with the sources of the surface water (and thus the direct cause of temperature variations) during warming and cooling periods (Colton 1968). Recent papers by Bowman and Wunder- (1977) and Wright (1976) and the classic works of elow (1933) and Bigelow and Sears (1935) provide background information to separate water masses and to establish the boundary between shelf water and slope er in the area discussed in this paper. The shelf-slope water boundary is usually in close proximity to the 100 m isobath in all seasons and can be represented by the 10°C isotherm (Wright 1976); these criteria will be d in part to define the causes of observed temperature changes since 1964. A paper by Colton and Stoddard (1973) based on 1940-66 mean temperatures can be d for comparing annual and long-term mean temture conditions.

Changes in physical and chemical properties of the oceans, including temperature, can directly or indi-ly affect fish and shellfish in numerous ways, but erally, there is a noticeable lack of ecological understanding of temperature effects (Brett 1969). Beltz et al. (1974) observed that over 7,000 papers have presented ence of biothermal relationships, but comparatively few of these involved bottom-water temperatures in the marine environment. Probably the best single reference on the effects of the thermal environment on marine fisheries are the contributions to a symposium held in Rome in 1964 by the International Commission for the Northwest Atlantic Fisheries (1965). Collectively these papers emphasize the need for basic ecological knowledge essential for an adequate understanding of events in the life history of fishes. The use of long-term temperature data may be helpful, either by itself or as a contributing factor in quantitative models, in gaining this understanding.

Because potential users of the following data may require actual temperature values instead of graphical data, certain of the figures and tables involve some redundancy of my analyses. The additional information is considered justified if it will encourage others to examine and use the presented data.

DATA AND METHODS

The data were collected during the period 1964-76 on surveys designed and conducted by the National Marine Fisheries Service, Woods Hole, Mass., (Grosslein 1969) to determine the distribution and relative abundance of groundfish at randomly selected stations, from Cape Hatteras to Cape Cod (Fig. 1). Approximately 125 bottom-water temperatures were obtained during each cruise, mostly at depths between 30 and 200 m, with either mechanical or expendable bathythermographs, the latter being used after 1969.

For analytical purposes, this area, known as the "Middle Atlantic Bight" (Bigelow 1933), was divided into subareas: Cape Cod to Hudson Canyon, termed the Northern Bight; and Hudson Canyon to Cape Hatteras, termed the Southern Bight. There was no sampling south of Hudson Canyon prior to the autumn of 1967 and spring cruises did not commence until 1968.

Methods and rationale for analysis are fully described by Davis (1978). Briefly, the indices derived for

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rtheast Fisheries Center Woods Hole Laboratory, National Marine Fisheries Service, NOAA, Woods Hole, MA 02543.

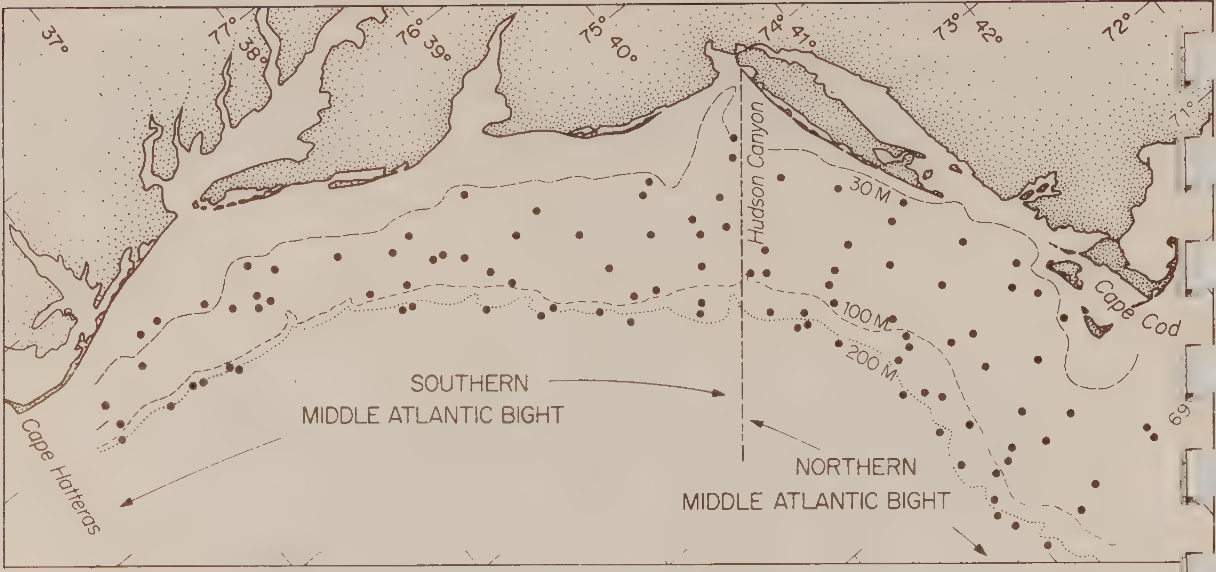


Figure 1.—Middle Atlantic Bight boundaries used in analysis of bottom-water temperature data. (Dots represent typical distribution of randomly selected bottom temperature stations.)

each cruise are based on the percentage of survey area represented by 2°C temperature contour intervals or temperature class intervals (TCI's) (Figs. 2, 3). The midpoint temperature of each TCI was multiplied by the percentage area within that TCI and their total product was divided by 100 to obtain a mean index for each cruise (Tables 1-4). The derived indices are based solely on an areal basis, but the stratified random sampling design allowed representative sampling by depth and geographic areas during each cruise. Since no attempt was made to determine absolute temperature indices, and the same geographic areas were randomly sampled during each cruise, the method chosen for determining relative temperature variations seems justified. A more precise estimate of relative bottom temperatures and elimination of possible bias associated with depth may have been analyzed. However, analytical data was not adequate for all the cruises and my major objective was to determine general temperature indices for rather large geographical areas during the entire seasonal time-series of data collection.

In order to determine year-to-year variation, the observed indices were adjusted by basing individual indices on a time-series mean sampling or reference date for each season (Table 5). Based on charts from Colton and Stoddard (1973) these seasonal reference dates closely approximate the timing of the annual minimum and maximum bottom-water temperature conditions expected in both subareas. Plots of annual bottom-water temperature cycles based on average temperature data by 10-day intervals at Nantucket Shoals and Five Fathom Bank Lightships during 1956-70 from Chase (1972) were used to calculate adjusted temperature values for the Northern Bight and the Southern Bight, respectively. The mean temperatures observed on each cruise were adjusted by adding or subtracting the ference in the mean temperatures at the appropriate lightship on the seasonal reference date and on the mid- date of each cruise. The magnitudes of the adjustme were usually ±0.2°C for the Northern Bight and ±0. for the Southern Bight, but differences as great as 2.8°C were noted in 1970 when three cruise mid-samp dates were approximately 1 mo earlier or later t their respective seasonal reference dates (Tables 5, 6, 8; Figs. 4, 7, 8). These large differences between observed and adjusted data clearly indicated the need for adjustments in order to make meaningful comparis of annual temperature variations. Since a comprehensive analysis of climatological and/or hydrographical conditions which might have revealed the factors sponsible for the large differences between observed adjusted data was beyond the scope of my investigation, these differences are attributed to the asynoptic seasonal sampling in certain years, e.g., 1970 (Table

The observed indices may be considered in measurements of the thermal environment and are particularly relevant to synoptic biological obser tions. The primary objective of the adjusted indices i measure the relative annual variations that have occurred during each spring and autumn in order to reveal any warming or cooling trends that may have occurr

Species distribution charts and catches by numb and pounds landed per ½ h tow observed during the same research cruises that temperature data were collected since 1967 were examined to determine possible effects of the observed temperature chan Examples of several of these relationships are briefly described in the Discussion section. Further analyses these observations are currently being conducted other members of the Woods Hole Laboratory staff.

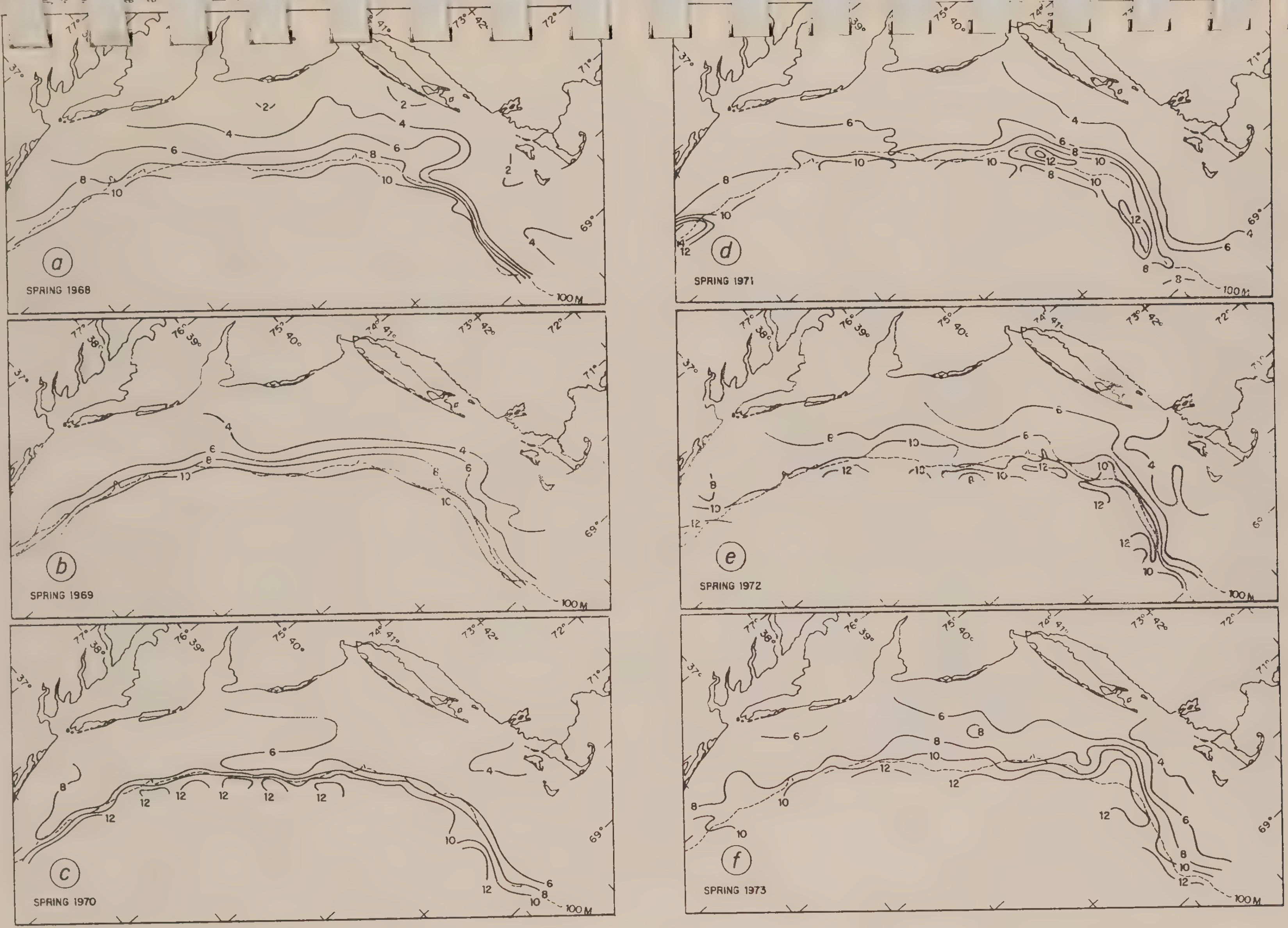

a
SPRING 1968
b
SPRING 1969
c
SPRING 1970
d
SPRING 1971
e
SPRING 1972
f
SPRING 1973
100 M
37°
38°
39°
40°
41°
42°
69°
71°
72°
73°
74°
75°
76°
77°
2
4
6
8
10
12

Figure 2.—Distribution of bottom-water temperatures (°C) in the Middle Atlantic Bight during spring 1968-76.

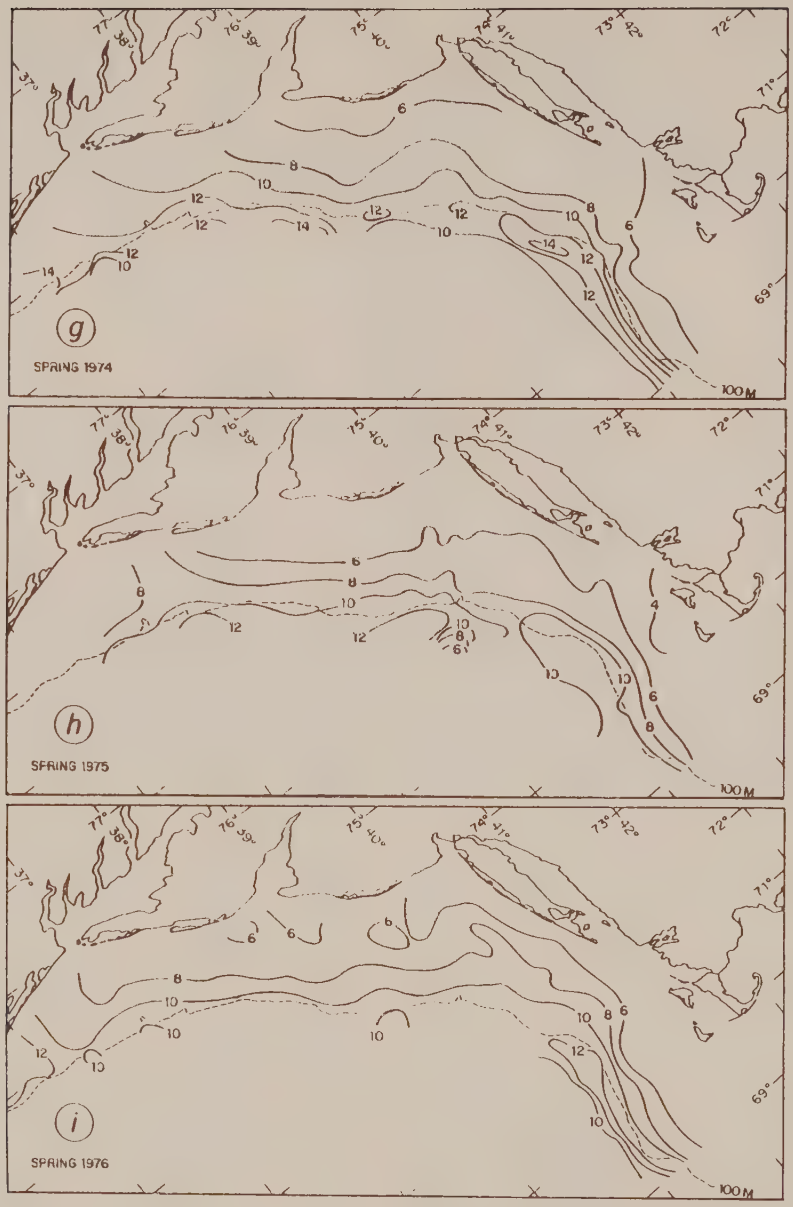


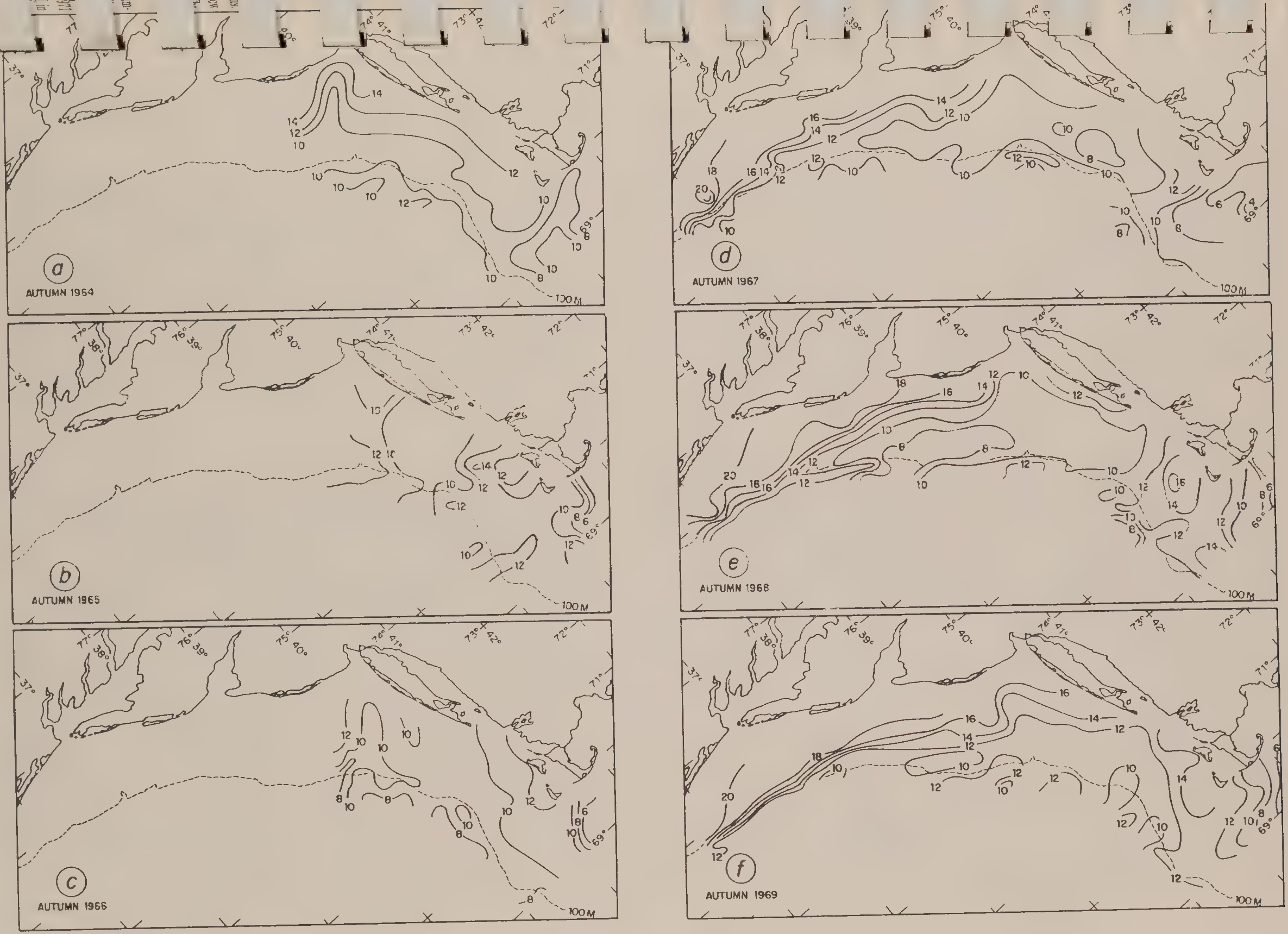
Figure 2.—Continued.

TEMPERATURE OBSERVATIONS

Northern Middle Atlantic Bight

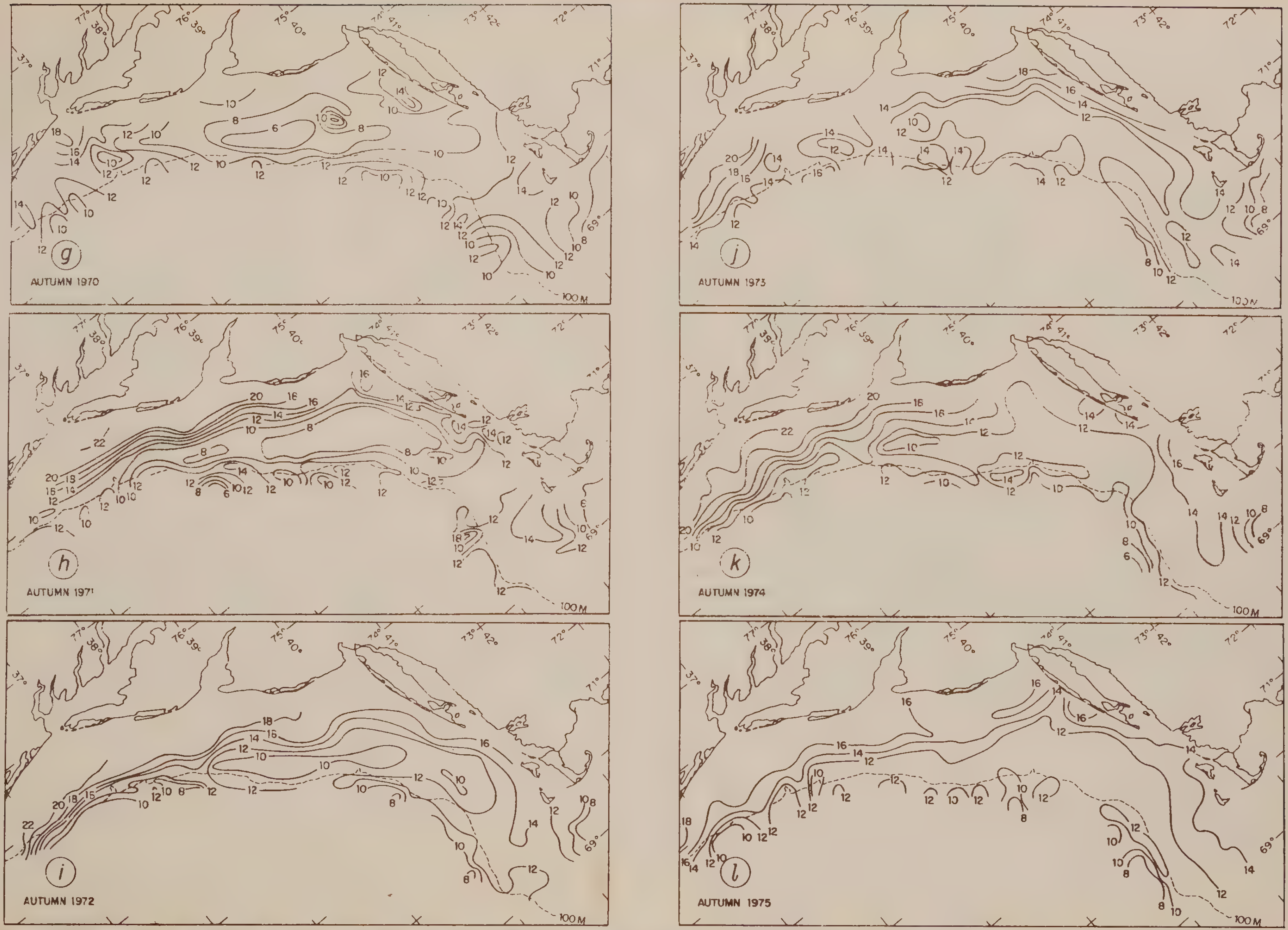
Spring 1968-76.—The Northern Bight spring temperatures are represented in Figure 4 and Table 6 which show both the year-to-year variations and the 9-yr means. The lowest and highest adjusted temperatures were 5.1°C in 1970 and 8.3°C in 1976 and the series clearly illustrates a warming trend since 1970. The observed temperatures coincide closely with the adjusted values in all years except 1970 and 1974 (when the cruises were 20-30 days later than usual) but generally show the same trends. The adjusted time-series mean of 6.7°C was 0.2°C less than the mean of the observed condit Both adjusted and observed temperatures were belo average prior to 1972 and above average for 1972. spring anomalies are summarized in Figure 5 Table 7.

The frequency distribution of TCI's in years with similar observed indices shows an inconsistency in their tive percentages (Table 1). The TCI percentages quite similar in the cold years of 1969 (6.0°C) and 197 (5.9°C) but quite different, especially the 6°-8°C TCI, i the warm years of 1974 (8.1°C) and 1976 (8.2°C). O average, slope water, identified here as >10°C, acc for 20% of the total bottom thermal environment. On th



a
AUTUMN 1964
b
AUTUMN 1965
c
AUTUMN 1966
d
AUTUMN 1967
e
AUTUMN 1968
f
AUTUMN 1969
37°
77° 38°
76° 39°
75° 40°
74° 41°
73° 42°
72°
71°
69°
100 M

Figure 3.—Distribution of bottom-water temperatures (°C) in the Middle Atlantic Bight during autumn 1964-76.



77°
38°
37°
76°
39°
75°
40°
74°
41°
73°
42°
72°
71°
69°
100 M
g
AUTUMN 1970
h
AUTUMN 1971
i
AUTUMN 1972
j
AUTUMN 1973
k
AUTUMN 1974
l
AUTUMN 1975

Fig —Con 1.

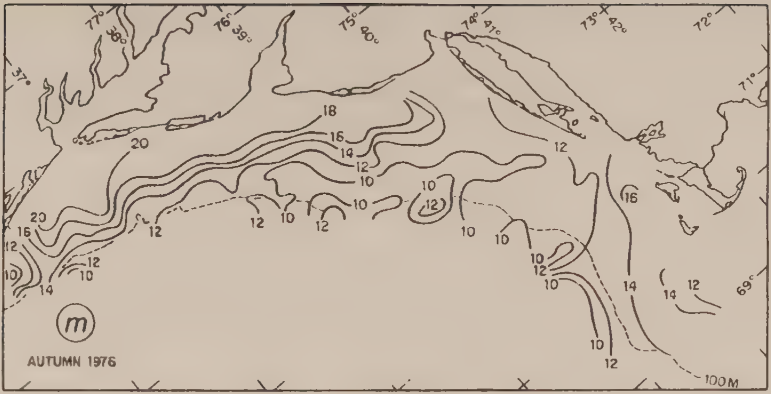


Figure 3.—Continued.

ɔle 1.—Percentages of temperature class intervals (TCI's) in he northern Middle Atlantic Bight during spring 1968-76.

		TCI						Observed
		2°-	4°-	6°-	8°-	10°-	12°-	index
ar	2°C	4°C	6°C	8°C	10°C	12°C	14°C	(°C)
	3	43	16	12	8	18	0	5.7
		36	21	14	15	14	0	6.0
		5	68	7	11	8	2	6.2
71	0	39	21	4	10	14	2	5.9
72	0	12	37	21	10	12	8	6.9
		11	34	16	11	15	12	7.3
		0	19	43	11	19	8	8.1
75		4	29	30	15	22	0	7.4
76	0	2	26	20	21	24	7	8.2
		17	30	20	12	16	4	6.9

ɔle 2.—Percentages of temperature class intervals (TCI's) in ıe northern Middle Atlantic Bight during autumn 1964-76.

	TCI						Observed
	6°-	8°-	10°-	12°-	14°-	16°-	index
ar	8°C	10°C	12°C	14°C	16°C	18°C	(°C)
	1	40	44	12	3	0	10.5
	0	33	53	14	0	0	10.6
56	0	1	67	32	0	0	11.6
57	12	45	39	4	0	0	9.7
	0	34	30	25	11	0	11.3
	0	7	45	32	16	0	12.1
	2	27	44	26	1	0	10.9
71	11	11	38	32	8	0	11.3
72	0	7	28	44	21	0	12.6
	1	4	33	47	15	0	12.4
	0	5	36	44	15	0	12.4
	1	2	57	34	3	2	11.7
76	0	10	32	35	23	1	12.6
	2	17	42	29	9	<1	11.5

reme, water <4°C averaged about 17% of the its high variability (0-46%) probably influences n conditions as much as the more steady (10-31%) oachment of slope water onto the continental shelf. est annual percentages of water >10°C (1976) C (1968) resulted in the warmest and coldest ins, respectively.

Table 3.—Percentages of temperature class intervals (TCI's) in the southern Middle Atlantic Bight during spring 1968-76.

	TCI							Observed
	2°-	4°-	6°-	8°-	10°-	12°-	14°-	index
Year	4°C	6°C	8°C	10°C	12°C	14°C	16°C	(°C)
1968	21	30	24	20	5	0	0	6.2
1969	27	37	12	10	14	0	0	5.9
1970	0	24	52	11	8	5	0	7.4
1971	2	38	31	21	5	1	1	6.9
1972	0	14	25	35	23	3	0	8.5
1973	0	17	45	21	15	2	0	7.8
1974	0	3	21	23	36	17	0	9.9
1975	0	24	25	29	16	6	0	8.1
1976	0	8	33	25	29	5	0	8.8
Mean	6	22	30	22	17	4	<1	7.7

Autumn 1964-76.—Bottom temperatures during the autumn in the Northern Bight fluctuated quite dramatically between years since 1964 (Fig. 6, Table 6). Except for a decline in 1975, a warming trend is indicated with maximum adjusted temperatures of 12.6°-12.8°C occurring since 1972. Most dramatic changes in the adjusted indices are the decrease from 12.5°C in 1966 to a minimum of 9.7°C in 1967 followed by an increase to 11.2°C in 1968. Adjusted and observed temperatures exhibited nearly the same annual variations which resulted in nearly identical 13-yr means of 11.6°C and 11.7°C, respectively. The autumn anomalies are shown in Figure 5 and Table 7.

In most cases, years of the same or closely similar observed temperatures had similar TCI percentages (Table 2). The coldest year (1967) had no water >14°C and all years (1969, 1972, 1973, 1974, 1976) that had indices >12°C had only 1% or less of water <8°C and only 10% or less of water <10°C. The 10°-12°C TCI usually dominated in all years and averaged 42% of the total bottom area during the time series.

Southern Middle Atlantic Bight

Spring 1968-76.—Adjusted bottom-water temperatures in the spring in the Southern Bight are characterized by large annual variations and a general warming

Table 4.—Percentages of temperature class intervals (TCI's) in the southern Middle Atlantic Bight during autumn 1967-76.

	TCI										Observe index
Year	4°-6°C	6°-8°C	8°-10°C	10°-12°C	12°-14°C	14°-16°C	16°-18°C	18°-20°C	20°-22°C	22°-24°C	(°C)
1967	0	0	27	29	12	12	16	4	0	0	12.5
1968	0	14	22	18	10	9	8	19	0	0	12.6
1969	0	0	7	21	14	7	18	33	0	0	15.1
1970	6	17	28	21	23	3	1	0	0	0	9.9
1971	0	13	14	27	13	7	8	7	9	1	12.7
1972	0	0	9	17	10	8	18	20	16	2	15.9
1973	0	0	2	25	25	32	8	7	1	0	13.9
1974	0	0	2	29	30	13	11	6	8	0	13.9
1975	0	0	5	29	15	26	26	0	0	0	13.9
1976	0	0	16	25	14	11	12	15	7	0	14.0
Mean	<1	4	13	24	17	13	13	11	4	<1	13.4

Table 5.—Middates of sampling bottom-water temperature data in the Middle Atlantic Bight. Means of sampling dates (bottom line) used as the bases for adjusted indices (see text).

	Southern New England		Middle Atlantic Bight	
Year	Spring	Autumn	Spring	Autumn
1964	No cruise	26 Oct.	No cruise	No cruise
1965	No cruise	11 Nov.	No cruise	No cruise
1966	No cruise	10 Nov.	No cruise	No cruise
1967	No cruise	24 Oct.	No cruise	24 Oct.
1968	15 Mar.	16 Oct.	10 Mar.	15 Oct.
1969	11 Mar.	12 Oct.	10 Mar.	13 Oct.
1970	20 Apr.	20 Oct.	26 Apr.	7 Sept.
1971	12 Mar.	8 Oct.	4 Apr.	8 Oct.
1972	26 Mar.	8 Oct.	13 Mar.	2 Oct.
1973	22 Mar.	7 Oct.	26 Mar.	1 Oct.
1974	1 Apr.	6 Oct.	18 Mar.	29 Sept.
1975	6 Mar.	19 Oct.	13 Mar.	29 Oct.
1976	8 Mar.	11 Oct.	17 Mar.	8 Oct.
Mean	20 Mar.	18 Oct.	22 Mar.	8 Oct.

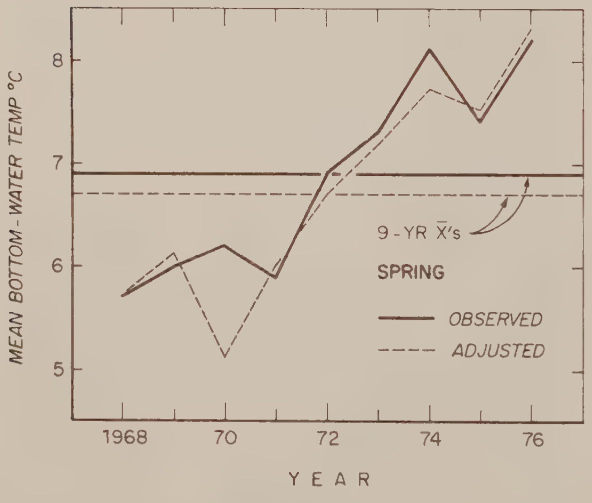


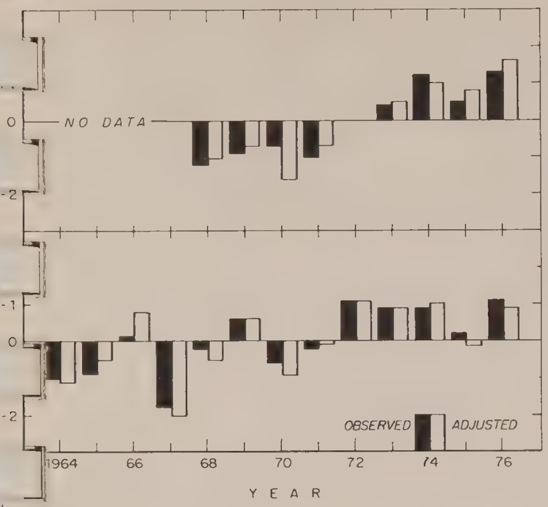
Figure 4.—Observed and adjusted annual and long-term mean bottom-water temperatures in the northern Middle Atlantic Bight during spring 1968-76.

Table 6.—Observed and adjusted mean bottom-water tempe in the northern Middle Atlantic Bight during spring 1968 autumn 1964-76.

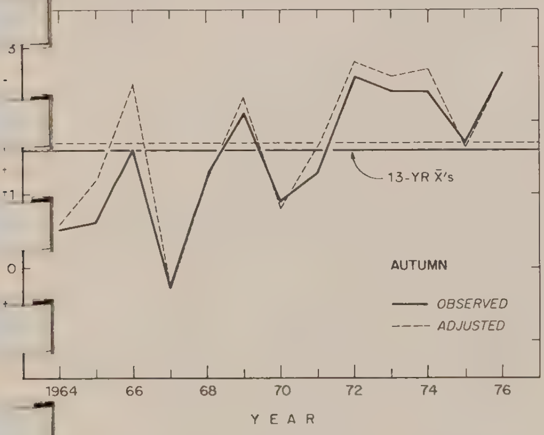
	$\bar{x}$ spring temperature (°C)			$\bar{x}$ autumn tempera	
Year	Observed	Adjusted	Change	Observed	Adjusted
1964		No cruise		10.5	10.6
1965		No cruise		10.6	11.2
1966		No cruise		11.6	12.5
1967		No cruise		9.7	9.7
1968	5.7	5.7	0	11.3	11.2
1969	6.0	6.1	+0.1	12.1	12.3
1970	6.2	5.1	−1.1	10.9	10.8
1971	5.9	6.0	+0.1	11.3	11.6
1972	6.9	6.7	−0.2	12.6	12.8
1973	7.3	7.2	−0.1	12.4	12.6
1974	8.1	7.7	−0.4	12.4	12.7
1975	7.4	7.5	+0.1	11.7	11.6
1976	8.2	8.3	+0.1	12.6	12.6
Mean	6.9	6.7	+0.2	11.5	11.7

Table 7.—Bottom-water temperature anomalies in the ern Middle Atlantic Bight during spring 1968-76 and a 1964-76.

	Spring anomalies (°C)		Autumn anomalies	
Year	Observed	Adjusted	Observed	A
1964		No cruise	−1.0	−1
1965		No cruise	−0.9	−0
1966		No cruise	+0.1	
1967		No cruise	−1.8	
1968	−1.2	−1.0	−0.2	
1969	0.9	0.7	+0.6	+0
1970	−0.7	−1.6	−0.6	−0
1971	−1.0	−0.7	−0.2	
1972	0	0	+1.1	
1973	+0.4	+0.5	+0.9	
1974	+1.2	+1.0	+0.9	+1
1975	+0.5	+0.8	+0.2	
1976	+1.3	+1.6	+1.1	
$\bar{x}$ indices	6.9	6.7	11.5	11



ure 5.—Observed and adjusted mean bottom-water temperature s in the northern Middle Atlantic Bight during spring nd autumn 1964-76. The "O" base lines are based on the onal time-series mean temperatures during each season.



ure 6.—Observed and adjusted annual and long-term mean om-water temperatures in the northern Middle Atlantic Bight utumn 1964-76.

nd over the data period (Fig. 7, Table 8). The lowest highest adjusted indices were 4.6°C in 1970 and n 1974 and the 9-yr mean was 7.5°C. Large year- differences were also prevalent among the erved indices and except for 1970 when the spring ise was nearly a month later than average, the trends ilar to the adjusted values. The lowest observed as 5.9°C in 1969 and the highest index was 9.9°C 1974.

ummarization of the annual spring anomalies (Fig. 8,) shows that all years before 1972 were below and aining years to 1976 were above the 9-yr average. he two coldest years, 1968 and 1969, had no water 2°C and relatively large amounts of water <4°C while m years of 1972-76 had none of this cold water y moderate amounts of this warm water (Table 3). On the average the TCI distribution did not vary much in the 4°-12°C range but was slightly dominated by the 6°-8°C TCI.

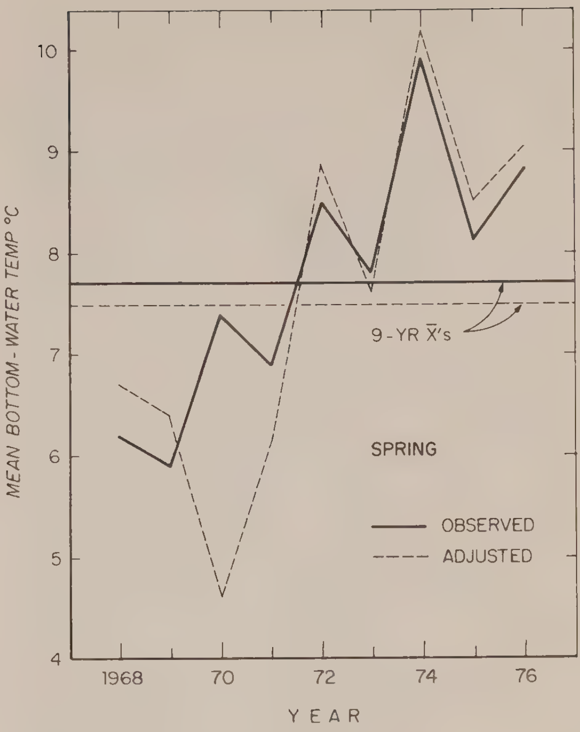


Figure 7.—Observed and adjusted annual and long-term mean bottom-water temperatures in the southern Middle Atlantic Bight during spring 1968-76.

Table 8.—Observed and adjusted mean bottom-water temperatures in the southern Middle Atlantic Bight during spring 1968-76 and autumn 1967-76.

	$\bar{x}$ spring temperature (°C)			$\bar{x}$ autumn temperature (°C)		
Year	Observed	Adjusted	Change	Observed	Adjusted	Change
1967		No data		12.5	12.6	+0.1
1968	6.2	6.7	+0.5	12.6	12.9	+0.3
1969	5.9	6.4	+0.5	15.1	15.3	+0.2
1970	7.4	4.6	−2.8	9.9	12.1	+2.2
1971	6.9	6.1	−0.8	12.7	12.7	0
1972	8.5	8.9	+0.4	15.9	15.7	−0.2
1973	7.8	7.6	−0.2	13.9	13.6	−0.3
1974	9.9	10.1	+0.2	13.9	13.6	−0.3
1975	8.1	8.5	+0.4	13.9	15.0	+1.1
1976	8.8	9.0	+0.2	14.0	14.0	0
Mean	7.7	7.5		13.4	13.8	

Autumn 1967-76.—The observed, adjusted, and 10-yr mean bottom-water temperatures are shown in Figure 9 and illustrate the extreme variations that occurred in the Southern Bight during the autumn series. Except for 1970 and 1975 when the cruises were about 30 days before and 20 days after the autumn reference date, the observed and adjusted values were relatively equal and show the same variability. The largest decreases (5.2°C

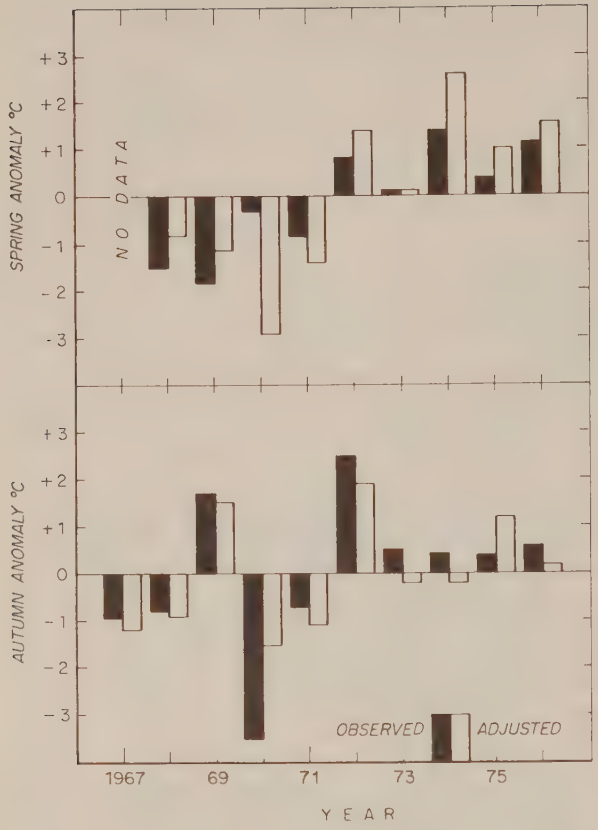


Figure 8.—Observed and adjusted mean bottom-water temperature anomalies in the southern Middle Atlantic Bight during spring 1968-76 and autumn 1967-76. The "O" base lines are based on the seasonal time-series mean temperatures during each season.

Table 9.—Bottom-water temperature anomalies in the southern Middle Atlantic Bight during spring 1968-76 and autumn 1967-76.

	Spring anomalies (°C)		Autumn anomalies (°C)	
Year	Observed	Adjusted	Observed	Adjusted
1967	No data		−0.9	−1.2
1968	−1.5	−0.8	−0.8	−0.9
1969	−1.8	−1.1	+1.7	+1.5
1970	−0.3	−2.9	−3.5	−1.7
1971	−0.8	−1.4	−0.7	−1.1
1972	+0.8	+1.4	+2.5	+1.9
1973	+0.1	+0.1	+0.5	−0.2
1974	+1.2	+2.6	+0.5	−0.2
1975	+0.4	+1.0	+0.5	+1.2
1976	+1.1	+1.5	+0.6	+0.2
$\bar{x}$ indices	7.7	7.5	13.4	13.8

for observed and 3.2°C for adjusted) was in 1970, the coldest autumn, while the largest increases (3.3°C for observed and 3.1°C for adjusted) was in 1972, the warmest autumn. The 10-yr adjusted mean index was 13.8°C and the observed mean was 13.4°C.

Figure 8 and Table 9 also show the autumn anomalies which, except for 1969, were negative in the first 5 yr of the series and positive or only slightly negative during the last 5 yr. The anomalies are quite simila spring series and generally reflect a warming tr this latter time period.

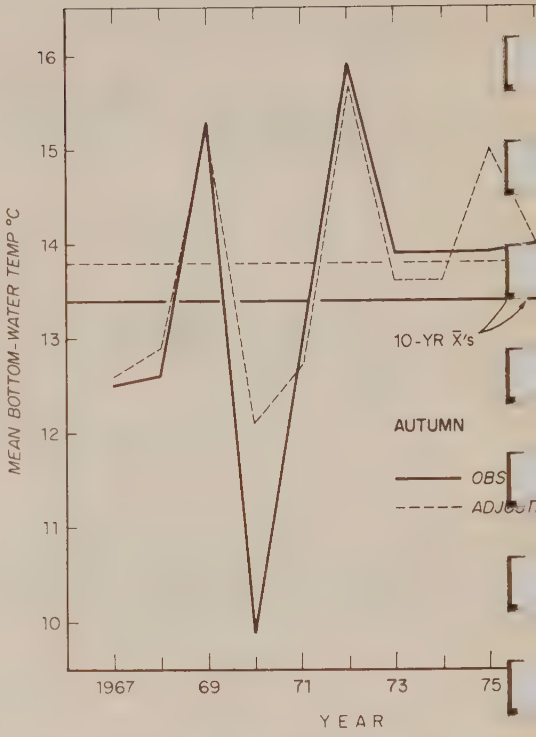


Figure 9.—Observed and adjusted annual and long-te bottom-water temperatures in the southern Middle Atla during autumn 1967-76.

On the average, the 10°-12°C TCI was the l (24%) while the remaining TCI's between 8° a averaged 11-17% to account for over 90% of the bottom layer (Table 4). Although the warm years 1 had the same or very nearly equal observed te tures, only the 10°-12°C TCI was similar in all 4 ing three nearly equally cold years—1967, 19 1971—the colder and warmer TCI's also varied con ably. One of the colder years (12.7°C in 1971) had more or equal amounts of water >16°C tha the warmer years (13.9°C in 1973-74) but was reg by a large amount (27%) of water <10°C.

DISCUSSION

Causes of Temperature Variations

Specific identification of water masses is specu this paper because supportive salinity data were nonexistent or unavailable at the time of this However, other investigations on the relationshi shelf-slope interface allow some general conclusions made based on temperature data alone, at least f spring observations. Based on the position of t isotherm (Figs. 2, 3), it can be seen that in th there was a greater encroachment of slope water on elf during years of higher temperatures. This increase ume of slope water coincided with a corresponding ase in volume of inshore cold water and subse- ently resulted in higher temperature indices for the en- re area. Wright (1976) summarized southern New nd temperature data from 1941 to 1972 and ved that the shelf-slope water boundary on the bot- m, as indicated by the 10°C isotherm, was usually 5-10 km south of the 100 m isobath in March and and only a couple of kilometers north or south of epth contour during October and November. He so observed that when the bottom position of the 10°C rm was farther offshore, the winter water tempera- inimum was low. Figure 2 shows that not only was e 10°C isotherm north of the 100 m contour during the ring warming trend of the 1970's, but that the slope was warmer than average in the last few years. mechanisms which might account for frontal ovements are not well understood, but wind stress ansport is thought to be significant, although usually ef duration (Crist and Chamberlin[2]). Size and fre- y of Gulf Stream warm core eddies may also cause gnificant variation in the slope front position by causing a ubsurface inshore flow of slope water as a compensation shore surface entrainment of shelf water (Morgan Bishop 1977).

In addition to water being carried onto the shelf from re, there is good evidence that some of the water g westward south of New England in the early pring originates in the Gulf of Maine-Georges Bank area Bigelow 1933; Beardsley et al. 1976). Drifts from the ct as cooling agents and indrafts of slope water as ing agents, but solar warming of the water, first and nost rapidly at the surface and next to land, is the outstanding feature in the spring (Bigelow 1933). During n, as surface cooling and mixing progresses and mmer thermocline is destroyed, bottom temperatures in the deeper strata increase to their seasonal max- ma.

ther striking feature of the hydrography in this area is the pool of cold bottom water that forms uring winter mixing, becomes isolated by summer tratification, and persists for several months (Bigelow Ketchum and Corwin 1964). This cold core may ex- from Cape Cod to the offing of Chesapeake Bay long the shelf edge and persist into September (Whit- 1970). Warming of these waters is associated with ture of higher-salinity offshore waters or lower- alinity surface waters (Ketchum and Corwin 1964). Isoated cold cores of bottom water were clearly evident the autumn cruises in both the Southern and ern Bights (Fig. 3) and their extent and minimum emperatures are reflected in the observed temperature ndices for each subarea. Especially notable is the mini- temperature observed in 1970 in the Southern Bight which was strongly influenced by a large cold pool with minimum temperatures of <6°C (Fig. 3g). The most pronounced effect of this cold pool in the Northern Bight occurred in 1967 when over half the subarea was covered by water <10°C with a relatively large inner core <8°C (Fig. 3d). During the warmest years (1972-74, 1976) and cold pool is either poorly defined, of small size, or made up of water >8°C.

Summarily, at least six phenomena directly or indirectly contribute to the bottom thermal environment of the continental shelf between Cape Cod and Cape Hatteras: 1) location of the slope front; 2) temperature of the slope water; 3) water drift from the east; 4) timing and extent of spring warming and autumn cooling of surface water; 5) size and frequency of Gulf Stream warm core eddies; and 6) size and temperature of the winter-formed "cold pool." To monitor and analyze these varied and complex phenomena presents a formidable task which cannot be accomplished solely on a basis of our survey cruises or data base.

Relationship of Temperatures East and West of Cape Cod

Although there is a rather abrupt general division between the hydrographic properties of the waters east and west of Cape Cod (Bigelow 1933; Parr 1933) these two regions have exhibited similar trends of temperature variability in recent years. The spring warming trend in the Gulf of Maine and on Georges Bank (Davis 1978) is especially similar to conditions in the Middle Atlantic Bight since 1973. Temperature variability in the Gulf of Maine is less because of the greater depths encountered there, but in many instances, the magnitude of annual changes were quite comparable in the other three areas. Bottom-water temperatures are strongly affected by the position of the shelf-slope boundary and vernal warming of shoal inshore waters and the effects of these phenomena have coincided with similar annual temperature trends in both regions during several years. A very rough estimate of average annual bottom temperature conditions (average of adjusted spring and autumn indices) since 1968 is depicted in Figure 10, and except for a couple of anomalous years, similar temperature trends are shown for each area.

Effects of Temperature Variations

Attempts to show environmental effects on fish year-class fluctuations by correlation techniques have generally failed because of difficulties of estimating both the year-class strength and the environmental factor (Gulland 1965). There is also difficulty in comparing distributional changes as related to changes in environmental conditions because population size contributes to the dispersive characteristics of many fishes, and there has been an apparent overexploitation of several fish stocks in the study area in recent years (Clark and Brown 1977). Despite these difficulties some evidence of natural biological changes seems apparent during this recent warm-

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[2] C, R. W., and J. L. Chamberlin. 1977. Temperature structure Continental Shelf and slope south of New England during 1976. manuscr., 27 p. Atlantic Environmental Group, National Marine Fisheries Service, NOAA, Narragansett, RI 02881.

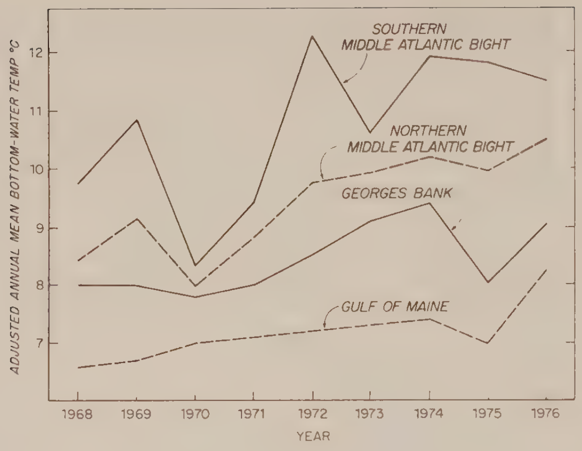

Figure 10.—Adjusted annual mean bottom-water temperature indices in four areas of the western North Atlantic continental shelf, 1968-76. Georges Bank and Gulf of Maine data are from Davis (1978).

ing period. Evidence collected during many of the same research cruises on which temperature data were collected revealed shifts in location and catch of the following species: 1) bluefish, *Pomatomus saltatrix;* relatively large catches in the autumn shifted from southern New England to Georges Bank, an area of unknown occurrence as reported by Bigelow and Schroeder (1953); 2) croaker, *Micropogonias undulatus,* occasional catches during warmer autumns but none during cold years off the North Carolina coasts; 3) mackerel, *Scomber scombrus;* catches normally widespread at most depths, confined mostly seaward of the 100 m contour during the cold springs of 1968-69 and 1971; 4) smooth dogfish, *Mustelus canis;* larger, more frequent and northward catches to southern New Jersey in the spring since 1972; 5) spiny dogfish, *Squalus acanthias;* a probable shift of part of the southern New England population onto Georges Bank during warm springs and catches decreased south of Hudson Canyon during the colder autumns; 6) spotted hake, *Urophycis regius;* generally avoid the coastal cold cells and their autumn catches are associated with the size and distribution of these waters; 7) fourspot flounder, *Hippoglossina oblonga;* during the coldest springs inshore catches small and irregular with concentrations synonymous with the 100 m contour; and 8) northern sea robin, *Prionotus carolinus;* same distributional behavior and catch characteristics as *H. oblonga.* It is not implied that these examples of changes in distributions and/or catches are explicitly related to changes in water temperature, but that some relationships probably exist since most of the species are not commercially fished and their distributions were determined on a basis of research ship surveys.

It should be noted that although Colton (1972) observed no significant changes in the distribution of four species of groundfish from Nova Scotia to Long Island during a cooling period, there was an extension of the southern range of American plaice, *Hippoglossoides platessoides,* and a contraction of the northern range of butterfish, *Peprilus triacanthus.* Also, Taylor e
(1957) found evidence of northward shifts in th
bution and abundance of several marine anima
a warming period in the Gulf of Maine, but there w
obvious alteration of the general marine fauna.

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Richard W. Langton and Ray E. Bowman

February 1980

U.S. DEPARTMENT OF COMMERCE
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Food of Fifteen Northwest Atlantic Gadiform Fishes

RICHARD W. LANGTON and RAY E. BOWMAN[1]

ABSTRACT

The food of 15 species of gadiform fishes occurring in the northwest Atlantic, from Cape Hatteras, N.C., to Nova Scotia, have been investigated for the years 1969-72. The populations of Atlantic cod, *Gadus morhua*; pollock, *Pollachius virens*; silver hake, *Merluccius bilinearis*; white hake, *Urophycis tenuis*; offshore hake, *Merluccius albidus*; and cusk, *Brosme brosme*; have reasonably similar diets, being primarily piscivorous. The red hake, *Urophycis chuss*, and spotted hake, *Urophycis regius*, also have similar diets and are mixed feeders, preying on both fish and invertebrates. The final seven species, haddock, *Melanogrammus aeglefinus*; longfin hake, *Phycis chesteri*; fourbeard rockling, *Enchelyopus cimbrius*; marlin-spike, *Nezumia bairdi*; longnose grenadier, *Coelorhynchus carminatus*; fawn cusk-eel, *Lepophidium cervinum*; and ocean pout, *Macrozoarces americanus*; prey almost exclusively on invertebrates.

INTRODUCTION

Investigations on the food habits of fish have been a major topic of research since the beginning of fishery re- ch as a scientific discipline. Since food availability mately controls production, the literature has become replete with papers describing, in detail, the prey of numerous species of fish. This vast literature has concen- ed on the more common commercially important cies, often at the expense of the lesser known but ecologically interesting fish. Among the Gadiformes described in this report the literature on the cod and had- k was found to be the most extensive (see Literature d), reflecting the importance of the fishery for these two animals, while comparative data on the food habits of fish such as the spotted hake, red hake, and the gren- rs is either scanty or completely lacking, especially for fish from the northwest Atlantic.

In recent years some authors have suggested that man- nent of a single fish species is untenable and that, in- d, the ecosystem must be considered as a whole (Gulland 1977). The commercially important species must be considered in relation to their role in the total marine ronment. Edwards (1976) has gone so far as to say , in the context of total ecosystem management, fish could be ignored as individual species and considered as a group occupying a specified feeding niche. These niches dependent upon the fishes' food habits which are, in , related to the morphology and size of the fish. Food related size classes for fish have been identified as "threshold lengths" by Parker and Larkin (1959) or ding stanzas" by Paloheimo and Dickie (1965) and r (1972). In order to develop such a management plan, however, it is first necessary to describe quantita- y the food of all the major fish populations occurring in the bounds of the ecosystem and evaluate the role of each stock relative to the other fish in that same system.

This report describes the food of 15 northwest Atlantic gadiform fish populations.

METHODS

Fish utilized for stomach contents analysis were collected during six bottom trawl survey cruises conducted on the following dates: 8 October-23 November 1969; 3 September-20 November 1970; 9 March-1 May 1971; 30 September-19 November 1971; 8 March-24 April 1972; and 27 September-20 November 1972. Collections were made with a # 36 Yankee otter trawl with rollers, 9 m legs, and standard 544 kg oval doors. The cod end and upper belly were lined with 13 mm mesh netting to retain smaller fish. A scheme of stratified random sampling was conducted within the five geographic areas of the northwest Atlantic (Fig. 1) and sampling continued over 24 h per day.[2]

A total of 9,158 stomachs was collected from 15 species of the Gadiformes. The fish were selected randomly from the bottom trawl survey catch. Stomachs were excised aboard ship; labeled according to species, cruise, and station; and preserved in 10% Formalin. The general plan was to obtain a random sample of the population for each species, without bias toward a specified length or sex. Juvenile fish were preserved whole. Only fish above a specified length are considered in this paper. The species collected and their minimum fork lengths are as follows: Atlantic cod, *Gadus morhua* (Linneaus), >20 cm; haddock, *Melanogrammus aeglefinus* (Linnaeus), >20 cm; silver hake, *Merluccius bilinearis* (Mitchill), >20 cm; pollock, *Pollachius virens* (Linnaeus),

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[1] rtheast Fisheries Center Woods Hole Laboratory, National Marine ies Service, NOAA, Woods Hole, MA 02543.

[2] Further details of the bottom trawl techniques may be obtained from the Resource Surveys Investigation, Northeast Fisheries Center Woods Hole Laboratory, National Marine Fisheries Service, NOAA, Woods Hole, MA 02543.

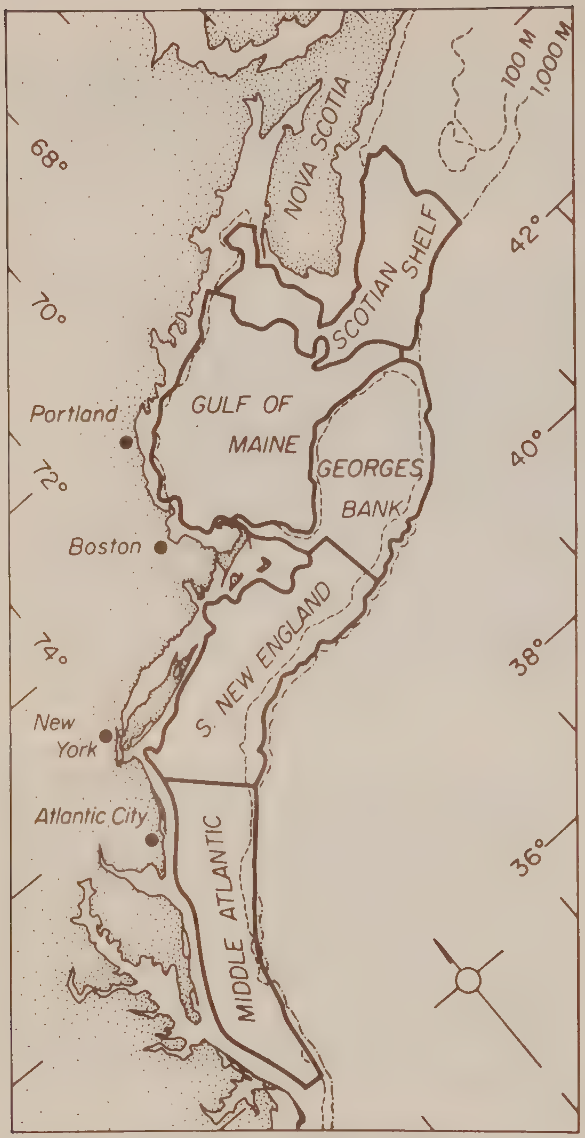


Figure 1.—Five geographic areas of the northwest Atlantic composing the sampling area for fish food studies, 1969-72.

>20 cm; red hake, *Urophycis chuss* (Walbaum), >20 cm; white hake, *Urophycis tenuis* (Mitchill), >20 cm; spotted hake, *Urophycis regius* (Walbaum), >10 cm; longfin hake, *Phycis chesteri* Goode and Bean, >10 cm; offshore hake, *Merluccius albidus* (Mitchill), >20 cm; fourbeard rockling, *Enchelyopus cimbrius* (Linnaeus), >10 cm; cusk, *Brosme brosme* (Müller), >20 cm; marlin-spike, *Nezumia bairdi* (Goode and Bean), >10 cm; longnose grenadier, *Coelorhynchus carminatus* (Goode), >10 cm; fawn cusk-eel, *Lepophidium cervinum* (Goode and Bean), >10 cm; and the ocean pout, *Macrozoarces americanus* (Bloch and Schneider), >10 cm.

In the laboratory, the preserved stomachs were opened and the contents emptied onto a fine mesh screen to permit washing without losing any food items. The vari prey items were manually sorted, identified to the lo est possible taxa (using a dissecting microscope w necessary), and damp dried on bibulous paper. E taxonomically distinct group was weighed to the neare 0.01 g on a Mettler balance, immediately after blottin Parasites in the stomach were included as part of stomach contents and are incorporated in the tables der "Other Groups."

Food

The food of each species of fish is summarized on weight basis as a percentage of the total weight of st ach contents. In the tables the subtotals for the m prey categories, i.e., subtotals for the major taxa, are set and italicized. The tables follow a standard format facilitate comparison of the food between species. In text the broader groupings of prey, as presented in tables, are discussed in detail. The percentage weight included in parentheses after the first mention of a pr group in order to quantify that particular prey's sig cance in the diet at that taxonomic level.

Dietary Overlap

Percentage similarity, as a measure of dietary ove lap, was calculated according to the formula of Shoryg (Ivlev 1961) as follows:

$$\text{P.S.} = 100-0.5\Sigma|a-b|$$

or, more simply, by summing the smaller value, in case the percentage weight, for all prey shared by the predators. Accordingly:

$$\text{P.S.} = \Sigma \min(a,b)$$

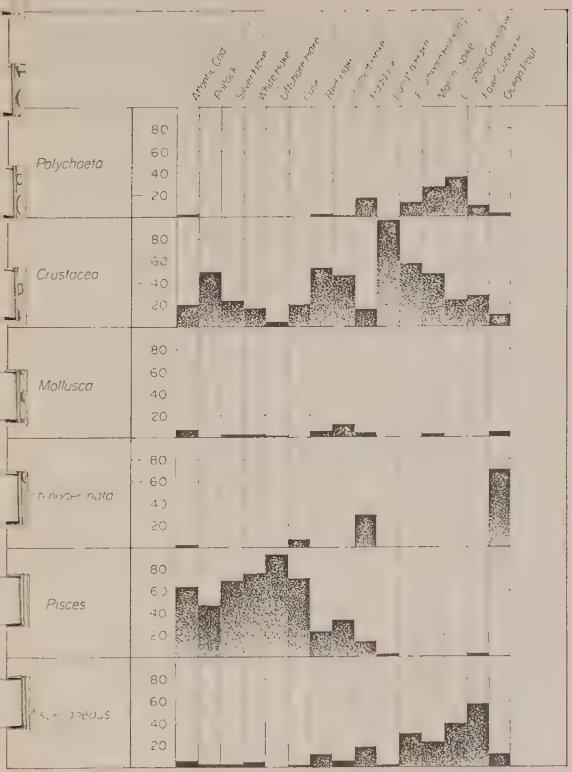
where: P.S. = percent similarity
a = percentage weight for a given prey group for predator A
b = percentage weight of the same prey group for predator B.

If a +, indicating <0.1% weight, was the sma value for any prey group in the table it was arbitrarily a signed a value equal to 0.05% for the calculations.

RESULTS

Food

Since the data are presented as percentages it possible to compare the food of each species directly an independently of the sample size. A detailed compa of food between species will be made later but firs consider separately the food of each species over the e tire study area (Table 1, Fig. 2) and then by the graphic areas (remaining tables) shown in Figure



ure 2.—Diagrammatic representation of prey of 15 gadiform es from five geographic areas in the northwest Atlantic for both spring and autumn bottom trawl survey cruises, 1969-72. Data are expressed as percentage weight.

Atlantic cod, *Gadus morhua*.—Atlantic cod preyed most heavily on fish (64.0%). Clupeidae (27.4%) were the st important prey, with the Atlantic herring, *Clupea engus* (16.7%), being the largest single contributor to the diet. The Gadidae made up 3.7% of the diet while the Scombridae, represented exclusively by the Atlantic ckerel, *Scomber scombrus*, composed 3.1% of the diet. Scorpaenidae contributed 3.2% to the diet, of which 2.6% was identified as the redfish, *Sebastes marinus*. er fish, the crustaceans were the next most important y group, making up 20.7% of the diet by weight. Decapods were the most important crustaceans totaling 16.6% of the diet. The Cancridae, represented by both species *ancer*, i.e., *C. borealis* (1.5%) and *C. irroratus* (1.4%), stituted a major part of the decapod prey totaling 4.7% of the diet. Pandalid shrimp (2.9%), particularly *Dichelopandalis leptocerus* (1.3%), and the toad crabs %) (family Majidae) of the genus *Hyas* also acnted for part of the decapod prey. Other phyla played a less important role. Mollusca composed only 7.6% of the prey with the pelecypods *Placopecten* (2.9%) and *ten* (1.2%) contributing the major fraction. Scallops e important only on Georges Bank and may represent the remains of scallops discarded by fishermen which were then preyed upon by cod. A similar situation observed for Georges Bank haddock by Wigley (1956). Polychaetes and echinoderms composed an even smaller percentage of the diet, 1.3 and 1.2%, respectively.

Pollock, *Pollachius virens*.—Almost one-half of the pollock's diet was fish (47.0%). The majority were clupeids (19.2%) which were identified as Atlantic herring (14.3%). Gadids (1.4%) were also preyed on, especially silver hake (1.2%), and in one instance a juvenile pollock was identified as part of the stomach contents. A small percentage of the stomach contents was made up of the scorpaenid *Sebastes marinus* (1.5%). "Other Pisces" (24.9%) accounted for over half the fish, and in this category eels (5.7%), lanternfish (2.0%), and the American sand lance, *Ammodytes americanus* (0.1%), could be identified. The remaining half of the diet consisted exclusively of crustaceans (50.8%). Euphausiids (35.3%) made up the majority of the Crustacea, with *Meganyctiphanes norvegica* contributing 26.5% of the diet by weight. Other species of euphausiids, such as *Thysanoessa inermis*, *T. longicaudata*, and *Euphausia krohnii*, were also identified in the stomach contents, but each of these species contributed <1% to the total weight of the prey consumed. Pandalid shrimp (2.5%) of the genera *Pandalus* (1.8%) and *Dichelopandalus* (0.5%) were of secondary importance, while *Pasiphaea multidentata* (10.0%), a pelagic shrimp, listed under "Other Decapoda," was of major significance. Annelids (polychaetes), molluscs, echinoderms, and other phyla contributed only 1% of the total diet.

Silver hake, *Merluccius bilinearis*.—The major proportion of the silver hake's diet was fish (70.9%). These hake preyed heavily on Atlantic mackerel (18.9%) and on clupeids (14.6%) such as the Atlantic herring (10.4%) and the alewife, *Alosa pseudoharengus* (4.2%). Silver hake were also cannibalistic; 3.4% of the Gadidae (7.1%) were silver hake. A large part of the fish could not be identified due to their state of digestion. Consequently, 30.1% of the prey was included under "Other Pisces." However, two groups in this category that could be recognized were the butterfish, *Peprilus triacanthus* (1.5%), and the lanternfish (family Myctophidae) (1.1%). Crustaceans formed the remaining bulk of the diet, 25.0%. Euphausiids (12.6%), such as *Meganyctiphanes norvegica* (7.4%), were the single most important crustaceans, but the pandalid shrimp, *Dichelopandalus leptocerus* (3.2%), was also of some importance. Other crustaceans which contributed to the diet were the two caridean shrimp: *Crangon septemspinosa* (1.4%) and *Pasiphaea* (2.0%). The only molluscs of any note were the cephalopods (2.2%), such as the squid *Loligo* (1.5%).

White hake, *Urophycis tenuis*.—White hake preyed heavily on fish (78.2%). The clupeids (12.5%) were the single most important group, with Atlantic herring making up 4.8% of the total diet. Gadids (10.7%) were also important, with silver hake (3.0%), red hake (0.8%), Atlantic cod (0.5%), haddock (0.5%), longfin hake (0.3%), and white hake (0.2%) all having been identified

Table 1.—Stomach contents of 15 northwest Atlantic gadiform fishes, expressed as percentage weigh

Prey/Predators	Atlantic cod		Pollock		Silver hake		White hake		Offshore hake		Cusk		Red hake	
POLYCHAETA	*1.3*		*0.1*		*0.2*		*0.2*		–		–		*2.9*	
Nereidiformia		1.2		+		0.2		0.1		–		–		1
Terebelliformia		+		–		–		–		–		–		+
Sabelliformia		–		–		–		–		–		–		0.1
Other Polychaeta		0.1		+		+		0.1		–		–		1
CRUSTACEA	*20.7*		*50.8*		*25.0*		*17.3*		*5.5*		*20.4*		*54.1*	
Amphipoda		0.5		0.1		0.4		0.1		–		+		7
Mysidacea		0.1		+		0.2		+		–		–		0.1
Euphausiacea		2.1		35.3		12.6		4.3		1.1		0.3		3.0
Pandalidae		2.9		2.5		5.3		9.1		2.5		4.1		12
Crangonidae		0.3		+		1.4		0.3		–		–		3
Axiidae		0.5		–		+		0.1		–		–		2.0
Paguridae		1.7		–		–		+		–		–		2.8
Majidae		2.1		–		–		–		–		1.7		0
Cancridae		4.7		–		0.1		0.3		–		–		5
Other Decapoda		4.4		10.4		2.6		2.3		1.9		11.6		13
Other Crustacea		1.4		2.4		2.4		0.8		–		2.7		4.9
MOLLUSCA	*7.6*		*0.4*		*2.2*		*2.1*		*0.9*		–		*6.3*	
Gastropoda		2.4		0.4		+		+		–		–		3
Pelecypoda		4.3		+		+		+		–		–		+
Cephalopoda		0.1		+		2.2		2.1		0.9		–		1.5
Other Mollusca		0.8		+		+		+		–		–		1.9
ECHINODERMATA	*1.2*		–		+		+		–		*6.8*		*0.6*	
Echinoidea		0.1		–		–		–		–		–		0
Ophiuroidea		0.6		–		+		+		–		6.8		
Other Echinodermata		0.5		–		+		–		–		–		0.5
PISCES	*64.0*		*47.0*		*70.9*		*78.2*		*93.4*		*71.5*		*25.3*	
Clupeidae		27.4		19.2		14.6		12.5		–		–		0
Gadidae		3.7		1.4		7.1		10.7		59.9		–		0
Scombridae		3.1		–		18.9		7.3		–		–		0
Scorpaenidae		3.2		1.5		–		1.7		–		–		–
Bothidae		0.3		–		–		–		–		–		0.5
Pleuronectidae		2.5		–		0.1		–		–		–		0
Other Pisces		23.8		24.9		30.1		46.0		33.5		71.5		2
Other groups	*0.4*		*0.5*		*0.1*		*0.1*		+		*0.2*		*0.8*	
Animal remains	*3.2*		*1.2*		*1.6*		*2.1*		*0.2*		*0.9*		*9.6*	
Sand and rock	*1.6*		*0.1*		+		+		–		*0.2*		*0.3*	
Number of stomachs		1,541		639		2,152		912		73		72		1,1
Percentage of empty stomachs		7.6		11.8		32.8		23.9		57.5		73.6		15.9
Mean weight per stomach (g)		27.9		18.2		2.5		18.0		2.4		3.2		2.3
Mean predator fork length (cm)		54.7		46.8		27.5		46.4		32.2		63.0		30
Number of sampling stations		291		160		222		177		14		43		1

in the stomach contents. The Atlantic mackerel (7.3%) was also important prey. Manfyy of the fish in the category "Other Pisces" (46%) were identified. Among those fish that could be identified to species were the argentine, *Argentina silus* (8.9%); wrymouth, *Cryptocanthodes maculatus* (0.8%); American sand lance (0.7%); and the butterfish (0.4%). Crustacea (17.3%) constituted most of the remainder of the diet. Of primary importance in this group were the pandalid shrimp (9.1%) of which four species have been identified, *Pandalus borealis* (2.2%), *Dichelopandalus leptocerus* (0.8%), *P. montagui* (0.5%), and *P. propinquus* (<0.1%). Euphausiids (4.3%), such as *Meganyctiphanes* (2.1%) and *Thysanoessa inermis* (0.3%), were also of some dietary significance. Rock crabs of the family Cancridae, i.e., *C. borealis* (0.2%) and *C. irroratus* (0.1%), were also identified as prey. Similarly, *Crangon* (0.2%) was identified as being of minor dietary importance. Among the "Other Decapoda," the red crab, *Geryon* (0.9%), was the most important. The only other category that contributed to the diet to any degree was cephalopods (2. of the genera *Loligo* (1.2%) and *Rossia* (0.1%).

Offshore hake, *Merluccius albidus*.—Offshore h preyed most heavily on fish, which accounted for 93 of the diet. The Gadidae contributed 59.9% of the die weight but none of the remains in the stomachs could b identified to lower than the family level. None of the remains in the "Other Pisces" category (33.5%) coul identified. Crustaceans were of secondary importanc (5.5%) and those that could be identified were the tw genera of pandalid shrimp (2.5%), *Dichelopand leptocerus* (2.4%) and *Pandalus* (0.1%). Euphau (1.1%), in particular *Meganyctiphanes norvegica* (0.9% were of little dietary significance. The only other deca pod identified was the pelagic shrimp *Pasiphaea* (0.

Cusk, *Brosme brosme*.—Cusk are primarily fis eaters (71.5%) but none of the prey species could b identified from the digested remains found in the s

collected during the spring and autumn bottom trawl survey cruises, 1969-72. (+ indicates present but <0.1%.)

Spotted hake	Haddock	Longfin hake	Fourbeard rockling	Marlin-spike	Longnose grenadier	Fawn cusk-eel	Ocean pout
0.5	*17.6*	–	*12.5*	*27.5*	*35.8*	*9.9*	*3.3*
0.1	2.0	–	–	–	–	2.4	3.0
–	1.6	–	–	–	–	–	+
–	1.3	–	–	–	–	–	–
0.4	12.7	–	12.5	27.5	35.8	7.5	0.3
47.5	*16.2*	*97.6*	*57.4*	*47.3*	*24.8*	*28.8*	*11.1*
7.3	6.4	+	1.0	7.8	–	4.9	5.6
+	0.1	–	+	4.0	–	–	–
+	2.6	60.3	1.0	+	–	–	–
3.9	1.4	8.7	9.6	–	–	–	+
4.1	0.1	–	40.7	–	–	6.4	+
+	0.9	–	–	–	–	0.3	–
0.1	0.4	–	–	–	–	+	0.5
+	0.3	–	–	–	–	–	0.3
6.8	0.1	–	–	–	–	–	2.9
20.8	1.8	15.4	4.7	27.5	23.6	0.7	0.8
4.5	2.1	13.2	0.4	8.0	1.2	16.5	1.0
11.5	*3.1*	–	–	*2.5*	–	*0.2*	*4.0*
0.1	0.3	–	–	–	–	–	0.6
0.2	2.3	–	–	2.5	–	–	3.3
11.2	0.2	–	–	–	–	–	–
+	0.3	–	–	–	–	0.2	0.1
+	*29.9*	*0.3*	–	–	–	*0.5*	*70.7*
–	5.7	0.3	–	–	–	–	64.9
–	21.6	–	–	–	–	0.2	5.3
+	2.6	–	–	–	–	0.3	0.5
34.2	*14.6*	*1.1*	+	–	+	*2.3*	*0.1*
–	12.9	–	–	–	–	–	–
4.3	0.3	–	–	–	–	–	–
3.3	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–
1.8	–	–	–	–	–	–	–
0.8	+	–	–	–	–	–	–
24.0	1.4	1.1	+	–	+	2.3	0.1
+	*1.0*	+	+	–	*2.8*	*29.8*	*2.7*
5.9	*8.9*	*1.0*	*30.1*	*22.4*	*36.6*	*28.5*	*4.0*
0.3	*8.7*	–	–	*0.3*	–	+	*4.1*
876	1,131	126	48	23	11	109	377
14.3	7.3	62.7	12.5	8.7	36.4	22.9	25.9
1.1	6.8	0.28	0.30	0.14	0.09	0.03	6.9
18.4	45.6	23.6	24.2	24.2	19.3	22.3	46.0
64	154	15	10	4	4	13	65

hs. Crustaceans are also a major prey category, 20.4%. ithin this group the toad crab (Majidae), *Hyas coarctatus* (1.7%), and several species of pandalid shrimp (4.1%), *Pandalus borealis* (3.3%), *P. propinquus* (0.1%), d *Dichelopandalus leptocerus* (0.7%), were identified. he Penaeidea (1.3%) also contributed a small amount to the diet. The brittle star, *Ophiopholus aculeata* (6.8%), was the only echinoderm preyed upon.

Red hake, *Urophycis chuss.*—Crustaceans (54.1%) were the major prey of red hake. A number of different milies contributed to the diet, with the Pandalidae 2.1%), especially the genus *Dichelopandalus* (7.1%), eing of primary importance. The galatheid crab, *Munida* (10.2%), which is included under "Other Deca- da," was also a major dietary component. Of second- y importance were the Cancridae (5.3%), particularly *C. irroratus* (2.1%); the Crangonidae (3.0%); the Axiidae (2.0%); *Axius* (0.6%); *Calocaris* (1.2%); and a variety of ferent species of amphipods (7.4%). Fish were also portant prey (25.3%). Clupeids (0.5%), Atlantic mackerel (0.4%), and the gadids (0.4%), such as silver hak (0.2%) and other red hake (0.2%), all contributed to th diet. The flatfish prey included Gulf Stream flounde *Citharichthys arctifrons* (0.5%), and the winter flounder, *Pseudopleuronectes americanus* (0.1%). Among th category "Other Pisces" (23.5%), the wrymouth (1.1% and the snake eel, *Omochelys cruentifer* (0.9%), wer identified. The Mollusca also contributed to the die (6.3%), however, most of them were not identifiable t below the class level. Of the gastropods consumed, onl *Buccinum* (0.2%) was identified to the genus level. Polychaetes were also a minor prey group (2.9%), and a fe genera that could be identified from the partially digested remains were *Arenicola* (0.1%), *Nephtys* (0.3% *Sabella* (0.1%), *Aphrodita* (0.1%), and *Ophioglycer* (0.1%).

Spotted hake, *Urophycis regius*.—Crustacea (47.5% form almost half the diet of spotted hake. Among th most important contributors to this assemblage o crustaceans were the galatheid crabs, *Munida iri*

(8.8%), *M. valida* (4.5%), remains of *Munida* (3.1%) that could not be identified to species, and other galatheids of the genus *Munidopsis* (1.7%). These crabs form the majority of the animals in the category "Other Decapoda" and were the single most important prey. Other crustaceans of some significance were amphipods (7.3%), especially the Hyperiidae (4.4%); the rock crab, *Cancer irroratus* (4.2%); the Crangonidae (4.1%), such as *Crangon* (3.9%) and *Pontophilus* (0.1%); the pandalid shrimp, *Dichelopandalus* (3.7%); and lastly, isopods (2.0%), which are included in the category "Other Crustacea." Fish constituted over one-third of the spotted hake's diet, 34.2%. Gadids (4.3%), such as silver hake (2.2%) and red hake (2.1%), were important prey, along with the Atlantic mackerel (3.3%). The bothid prey included the Gulf Stream flounder (1.8%), whereas the only member of the Pleuronectidae identified was the yellowtail flounder, *Limanda ferruginea* (0.5%). Fish, considered under the category "Other Pisces," that could be identified were cusk-eel (family Ophidiidae) (4.4%), lanternfish (family Myctophidae) (3.0%), primarily of the genus *Myctophum* (1.5%), and the snake eel (0.1%). The only other taxon that was of significance as prey is the Mollusca (11.5%). Within this phylum, Cephalopoda (11.2%) was the most important class. Two genera of squid were identified in the stomachs: *Loligo* (4.2%) and *Rossia* (0.4%). Most of the remaining cephalopods (6.6%) could not be identified.

Haddock, *Melanogrammus aeglefinus*.—Haddock fed on a variety of benthic invertebrates with echinoderms (29.9%) of the subclass Ophiuroidea (21.6%) being of major importance. The brittle stars *Ophiura* (6.2%) and *Ophiopholis* (5.5%) were the two most important prey items. Polychaetes, crustaceans, and fish all contributed about equally to the diet, 17.6%, 16.2%, and 14.6%, respectively. A number of different polychaetes were identified in the stomach contents, e.g., *Aphrodita* (0.5%), *Cistenidae* (0.2%), *Chone infundibulinformis* (0.1%), Sabella (0.1%), and *Nephtys* (0.1%). The single most important species was *Ammotrypane aulogaster* (3.8%) which accounted for more than one-fourth of the category "Other Polychaeta" (12.7%). Amphipods (6.4%), particularly gammaridean amphipods (4.2%), were the largest component of the crustacean prey. Other crustaceans of importance were euphausiids (2.6%), such as *Meganyctiphanes norvegica* (1.8%), and the pandalid shrimp (1.4%), *Pandalus* (0.7%) and *Dichelopandalus leptocerus* (0.5%). The importance of fish may be slightly overemphasized from the present results. The Clupeidae appear to be a major food source; however, the entire weight (12.9%) was due to the consumption of herring eggs rather than adult or juvenile fish. Finally, sand and rocks made up 8.7% of the stomach contents by weight, thus reflecting the haddock's benthic habits.

Longfin hake, *Phycis chesteri*.—The longfin hake preyed primarily on Crustacea, as this prey group made up 97.6% of the diet. However, the total quantity of prey examined was relatively small (35.28 g) although it represented 126 fish. Possibly a more extensive study of the food of this fish would broaden the spectrum of prey co sumed. Nevertheless, in this study the single most i portant prey item was the euphausiid, *Meganyctiphanes norvegica*, which constituted more than half (55.9%) of the diet. The only other crustacean identifi to the genus level was the shrimp, *Pandalus* (8.6%).

Fourbeard rockling, *Enchelyopus cimbrius*.—A large proportion of the diet of the fourbeard rockling w Crustacea (57.4%). The primary prey species w *Crangon septemspinosa* (40.7%). The pandalid shrimp, *Dichelopandalus leptocerus* (9.6%), was of secondary importance, while euphausiids (1.0%) and amphipo (1.0%) contributed little to the diet. Polychaetes (12.5% were also preyed upon but the only identifiable genus was *Ammotrypane* (3.3%). Unidentified animal remai made up 30.1% of the diet. This is due to the state of d gestion of the prey and also, possibly, because of the small total weight in the stomachs (14.4 g).

Marlin-spike, *Nezumia bairdi*.—This summary the food of the marlin-spike is based on only 23 fish and an extremely small weight (3.22 g) for the prey. The two most important prey groups were the crustacea (47.3%) and polychaetes (27.5%). The polychaete r mains could not be identified below the class level. Some of the crustaceans were identifiable, such as hippolyt shrimp, *Eualus pusiolus* (26.0%), which accounts f most of the animals included in "Other Decapoda Mysids, *Neomysis americana* (4.0%), the isopod, *Cirolina* (0.6%), and euphausiids (<0.1%) were the oth crustaceans that could be identified.

Longnose grenadier, *Coelorhynchus carminatus*.—As has been described for the marlin-spike, t summary of the food of longnose grenadier is based o small sample both in the number of fish analyzed and the total weight of prey. It is possible that the percentage composition of the diet would differ markedly if mo fish were available for analysis. From the available dat polychaetes and decapod shrimp were the only identifiable prey.

Fawn cusk-eel, *Lepophidium cervinum*.—The stomach contents of 109 fawn cusk-eel were examined, but the total weight of the prey amounted to only 3.27 g. For th reason the percentage weights listed in Table 1 should used more as a qualitative guide to the food since a smal change in weight could markedly influence the percentage composition of the diet. Bearing this precaution mind, the prey items are discussed below.

The most significant prey group was the crustaceans (28.8%). Within this group the "Other Crustacea" were the largest contributors, primarily the isopod, *Ciroli* (12.6%). A variety of different families of amphipods w found in the stomachs, the most important being the Gammaridae (4.6%). Other crustaceans that could be identified were two members of the *Crangonidae* (6.4 [*Crangon* (2.3%) and *Sabinea* (2.6%)], the munid cra

Munidopsis (0.7%), and the mud shrimp, *Calocaris* (0.3%). Polychaetes (9.9%) were moderately important, with a few identified to the genus level, such as *Nephtys* (1.8%), *Scalibregma* (1.0%), and *Nothria* (0.6%). "Other Groups" (29.8%) was the single most important category contributing to the stomach contents, and this was comprised of a large number of parasitic nematodes (29.4%).

Ocean pout, *Macrozoarces americanus*.—Ocean pout preyed most heavily on echinoderms (70.7%), the single most important species being the sand dollar, *Echinarachnius parma* (56.3%). Ophiuroids (5.3%), such as *Ophiopholis* (1.1%) and *Ophiura* (0.1%), were also identified in the stomach contents. Crustaceans (11.1%), most notably the rock crabs of the family Cancridae (2.9%), both *Cancer irroratus* (1.0%) and *C. borealis* (0.7%), and a number of different amphipods (5.6%) were also prey items. Polychaetes (3.3%) of the genus *Aphrodita* (3.0%) and the tunicate, *Cnemidocarpa mollis* (1.7%), which falls into the category "Other Groups," were other components of the diet.

Geographic Comparisons

The data on the food of the 15 species of Gadiformes for each of the five geographic areas (Fig. 1) in the northwest Atlantic are presented in the following text and/or Tables 2-11. In this section the data are compared and contrasted for each species in each of the five areas to emphasize similarities and differences in food over these broad geographic regions.

Atlantic cod, *Gadus morhua*.—In all of the geographic areas fish was the major prey of Atlantic cod with the Clupeidae generally being the most important (Table

Table 2.—Geographic breakdown of food of Atlantic cod, *Gadus morhua*, in the northwest Atlantic. Data are expressed as percentage weight, for fish collected during the spring and autumn bottom trawl survey cruises 1969-72. (+ indicates present but <0.1%.)

Prey	Middle Atlantic	Southern New England	Georges Bank	Gulf of Maine	Western Nova Scotia
POLYCHAETA	*0.1*	*6.4*	*1.1*	*0.3*	*0.8*
Nereidiformia	0.1	6.4	1.0	0.2	0.6
Terebelliformia	–	–	+	+	+
Sabelliformia	–	–	–	–	–
Other Polychaeta	–	+	0.1	0.1	0.2
CRUSTACEA	*10.2*	*20.9*	*15.2*	*26.1*	*27.6*
Amphipoda	+	1.6	0.7	0.1	0.1
Mysidacea	–	+	0.2	+	+
Euphausiacea	–	–	0.4	1.2	8.8
Pandalidae	0.1	0.7	3.1	2.8	3.9
Crangonidae	1.4	0.3	0.4	0.1	0.1
Axiidae	–	2.4	0.1	+	1.3
Paguridae	3.8	0.9	2.5	0.2	2.2
Majidae	–	+	1.5	0.2	7.4
Cancridae	2.8	12.8	4.4	5.9	–
Other Decapoda	–	1.6	0.7	14.1	1.7
Other Crustacea	2.1	0.6	1.2	1.5	2.1
MOLLUSCA	*0.6*	*1.9*	*15.6*	*0.7*	*0.6*
Gastropoda	–	1.4	4.7	0.3	0.3
Pelecypoda	–	0.4	9.4	0.1	+
Cephalopoda	–	+	+	0.3	+
Other Mollusca	0.6	0.1	1.5	+	0.3
ECHINODERMATA	–	*0.8*	*0.6*	*0.4*	*3.6*
Echinoidea	–	+	+	+	0.2
Ophiuroidea	–	0.3	0.3	0.2	1.9
Other Echinodermata	–	0.5	0.3	0.2	1.5
PISCES	*86.5*	*64.1*	*61.6*	*69.5*	*60.6*
Clupeidae	–	32.8	37.3	23.3	12.1
Gadidae	12.9	–	2.6	4.5	6.5
Scombridae	–	6.4	–	8.7	1.7
Scorpaenidae	–	–	–	11.6	0.9
Bothidae	–	1.9	0.3	–	–
Pleuronectidae	43.7	–	4.3	–	–
Other Pisces	29.9	23.0	17.1	21.4	39.4
Other groups	+	*0.1*	*0.6*	*0.3*	*0.3*
Animal remains	*2.6*	*4.8*	*2.7*	*2.2*	*5.4*
Sand and rock	+	*1.0*	*2.6*	*0.5*	*1.1*
Number of stomachs	7	79	667	347	441
Percentage of empty stomachs	0.0	6.3	6.9	8.6	8.1
Mean weight per stomach (g)	69.7	46.6	29.6	31.9	18.2
Mean predator fork length (cm)	82.0	65.8	50.3	57.7	57.9
Number of sampling stations	5	22	90	71	103

2). In the Middle Atlantic, however, only seven Atlantic cod stomachs were examined and yellowtail flounder (33.7%) was the most important prey. In Southern New England and on Georges Bank most of the clupeids could be identified as Atlantic herring (27.1 and 31.4%, respectively). The only other clupeid identified to species level was an alewife (0.9%), from Georges Bank.

A variety of other fish was eaten throughout the Northwest Atlantic and is listed by area as follows: Middle Atlantic—red hake (12.9%); winter flounder (10.0%); beardfishes, Polymyxiidae (9.0%); cusk-eels, Ophidiidae (6.4%); sand lance, *Ammodytes* (2.7%); and the longhorn sculpin, *Myoxocephalus octodecemspinosus* (1.5%). Southern New England—Atlantic mackerel (6.4%); windowpane, *Scophthalmus aquosus* (1.9%); Cryptacanthodidae (2.8%); the Cottidae (1.1%); and a seahorse, *Hippocampus* (0.2%). Georges Bank—yellowtail flounder (3.4%); American plaice, *Hippoglossoides platessoides* (0.9%); summer flounder, *Paralichthys dentatus* (0.1%); windowpane (0.2%); the rock gunnel, *Pholis gunnellus* (0.1%); sculpins such as the grubby, *Myoxocephalus aenaeus* (<0.1%), the longhorn sculpin (0.5%), and the mailed sculpin, *Triglops nybelini* (0.1%). Gulf of Maine—the scorpaenids, *Helicolenus dactylopterus* (1.9%) and *Sebastes marinus* (9.6%); Atlantic mackerel (8.7%); wolffish, *Anarhichadidae* (3.3%); *Argentina* sp. (3.2%); silver hake (1.6%); and the wrymouth (0.4%). Western Nova Scotia—sand lance (11.3%); gadids, including silver hake (1.7%), haddock (0.7%), and Atlantic cod (0.1%); Atlantic mackerel (1.7%); redfish (0.9%); wolffish (0.2%); and the rock gunnel (0.1%).

Crustacea were generally the second most important group of prey and, like fish, a variety of different crustaceans were consumed, but only the major groups will be discussed here. In the Middle Atlantic the only crustacean prey of any significance was hermit crabs, Paguridae (3.8%), and rock crabs (2.5%). Crustaceans composed 20.9% of the Atlantic cod's diet in Southern New England; and the rock crabs (12.8%), *Cancer borealis* (2.8%) and *C. irroratus* (1.8%), accounted for more than half of this group. On Georges Bank, rock crabs (4.4%) were again the most important crustacean prey but pandalid shrimp (3.1%) [i.e., *Dichelopandalus* (2.3%)], and hermit crabs, *Pagurus* (2.5%), also contributed to the diet. In the Gulf of Maine rock crabs (5.9%) and pandalid shrimp (2.8%) were again preyed upon but the red crab, *Geryon* (10.1%), was the most important decapod prey. Spider crabs (family Majidae) of the genus *Hyas* (7.4%) and euphausiids (8.8%), such as *Meganyctiphanes* (2.6%), were the primary crustacean prey in Western Nova Scotia. Of secondary importance were the Paguridae (2.2%) and the pandalid shrimp (3.9%), *Dichelopandalus leptocerus* (0.8%) and *Pandalus montagui* (0.3%).

Two other taxa were of some significance in two of the geographic areas. In Southern New England polychaetes of the suborder Nereidiformia made up 6.4% of the diet, and this was entirely due to the sea mouse, *Aphrodita*. The Mollusca accounted for 15.6% of the prey on Georges Bank. The pelecypods contributed most of the weigh (9.4%), with the scallops, *Placopecten* (6.3%) and *Pecten* (2.6%), accounting for the majority of the prey in th group but these scallops may be scallop remains dis carded by fishermen since only scallop viscera and no adductor muscles were found in the stomachs.

Pollock, *Pollachius virens*.—Because only six fish were collected for stomach content analysis in Souther New England and the Middle Atlantic, the followin discussion is limited to the other three areas (Table 3).

The major prey of pollock on Georges Bank and in Western Nova Scotia was crustaceans (71.6 and 61.2% respectively). In both of these areas euphausiids comprised more than one-half the diet. Of the euphausiids identified, *Meganyctiphanes norvegica* was the most important, contributing 46.6% of the diet on Georg Bank and 46.2% in Western Nova Scotia. Other euphausiids, such as *Thysanoessa longicaudata*, were preyed upon in both areas (3.6% on Georges Bank and <0.1% in Western Nova Scotia), but *Euphausia krohnii* (0.1% was only found in stomachs collected from Georges Ban Apart from euphausiids, pandalid shrimp, primarily *Pandalus* sp. (2.7% on Georges Bank and 2.9% in Western Nova Scotia), and "Other Decapoda" such *Pasiphaea* (4.0% in Western Nova Scotia) were the only other important Crustacea. Fish accounted for the remaining bulk of the diet and a number of differe species were identified in the stomach contents as f lows: Georges Bank—lanternfish (8.8%); the pearlside, *Maurolicus pennanti* (1.2%); silver hake (0.4%); and pollock (0.1%). Western Nova Scotia—the snake eel (5.5% redfish (1.3%); haddock (0.7%); silver hake (0.6%); blu back herring, *Alosa aestivalis* (0.5%); and the sand lance, *Ammodytes* (0.4%).

In the Gulf of Maine the emphasis shifted from Cr tacea (33.8%) to Pisces (64.9%) as the major prey ca gory. This difference was almost entirely caused by heavy predation on the Atlantic herring (29.4%). Few other fish, except for redfish (2.3%) and silver h (1.9%), could be identified from the partially digested mains. Crustaceans remained an important prey group but the groups composing the category differed fr those of Georges Bank and Western Nova Scotia. "Ot Decapoda" were the most important, with *Pasiphaea* being the largest single prey item (5.5%). Euphausiids also contributed to the diet and, again, *Meganyctipha* (6.7%) was the most important, although *Thysano inermis* (0.1%) was also present in the stomach contents. Finally, three species of pandalid shrimp were identified: *Dichelopandalus leptocerus* (0.9%), *P dalus borealis* (0.6%), and *P. montagui* (<0.1%).

Silver hake, *Merluccius bilinearis*.—Silver hake widespread with the result that stomachs were collected in reasonably large numbers from all geographic a (Table 4). In all five areas fish was the major prey but

Table 3.—Geographic breakdown of food of pollock, *Pollachius virens*, in the northwest Atlantic. Data are expressed as percentage weight, for fish collected during the spring and autumn bottom trawl survey cruises 1969-72. (+ indicates present but <0.1%.)

Prey	Middle Atlantic	Southern New England	Georges Bank	Gulf of Maine	Western Nova Scotia
POLYCHAETA	–	–	*0.1*	+	*0.1*
Nereidiformia	–	–	–	+	+
Terebelliformia	–	–	–	–	–
Sabelliformia	–	–	–	–	–
Other Polychaeta	–	–	0.1	+	0.1
CRUSTACEA	*92.7*	–	*71.6*	*33.8*	*61.2*
Amphipoda	–	–	0.5	+	+
Mysidacea	–	–	0.1	+	–
Euphausiacea	–	–	66.4	11.4	53.7
Pandalidae	–	–	2.9	2.1	3.1
Crangonidae	–	–	0.1	–	+
Axiidae	–	–	–	–	–
Paguridae	–	–	–	–	–
Majidae	–	–	–	–	–
Cancridae	–	–	–	–	–
Other Decapoda	–	–	0.4	16.0	4.2
Other Crustacea	92.7	–	1.2	4.3	0.2
MOLLUSCA	–	–	*1.6*	*0.1*	+
Gastropoda	–	–	1.6	–	–
Pelecypoda	–	–	–	–	+
Cephalopoda	–	–	–	0.1	+
Other Mollusca	–	–	–	–	–
ECHINODERMATA	–	–	–	–	–
Echinoidea	–	–	–	–	–
Ophiuroidea	–	–	–	–	–
Other Echinodermata	–	–	–	–	–
PISCES	*7.3*	*100.0*	*22.8*	*64.9*	*37.1*
Clupeidae	7.0	–	0.8	36.9	4.0
Gadidae	–	–	0.5	1.9	1.3
Scombridae	–	–	–	–	–
Scorpaenidae	–	–	–	2.3	1.3
Bothidae	–	–	–	–	–
Pleuronectidae	–	–	–	–	–
Other Pisces	0.3	100.0	21.5	23.8	30.5
Other groups	–	–	*1.3*	*0.3*	*0.3*
Animal remains	–	–	*2.6*	*0.8*	*1.3*
Sand and rock	–	–	+	*0.1*	+
Number of stomachs	5	1	206	203	224
Percentage of empty stomachs	20.0	0.0	2.9	12.8	18.8
Mean weight per stomach (g)	36.3	13.1	12.7	27.7	14.2
Mean predator fork length (cm)	51.0	82.0	38.2	66.4	44.6
Number of sampling stations	3	28	32	68	29

species of fish eaten differed. Gadids (13.5%) were of primary importance in the Middle Atlantic where silver [illegible]ke were heavily cannibalistic (12.6%). Yellowtail flounder (0.7%) was the only pleuronectid eaten and some of the fish in the "Other Pisces" category were the butterfish (0.9%); horned lanternfish, *Ceratoscopelus [illegible]derensis* (0.6%); and the longhorn sculpin (0.1%). In Southern New England the Gadidae (12.6%) were also important and silver hake were again cannibalistic [illegible]4%). The Atlantic mackerel (31.7%), however, was the [illegible]mary prey. "Other Pisces" included butterfish (4.8%), the sand lance, *Ammodytes* (<0.1%), and an unidentified member of the Cottidae (0.1%). Silver hake [illegible].1%) were again identified as prey on Georges Bank [illegible] their contribution to the diet was insignificant. The only other fish identified were lanternfish, Myctophidae (2.2%), and the snakeblenny, *Lumpenus lumpre[illegible]formis* (0.1%). Atlantic mackerel (28.0%); Atlantic herring (23.1%); alewife (9.4%); silver hake (1.4%); and butterfish (1.1%) were all preyed upon in the Gulf of Maine. In Western Nova Scotia the Gadidae (51.2%) were preyed on extensively but silver hake only composed 1.1% of the diet. None of the other fish were identified to species.

Crustacea formed the remaining bulk of the diet in all five geographic areas, and within this category the Euphausiacea and Pandalidae were the most important. In the Middle Atlantic, *Dichelopandalus* (8.2%) was the only pandalid shrimp identified. Most euphausiids (7.0%) were identified to the order level, however, those identified to the species level were found to be *Meganyctiphanes norvegica* (0.1%). The only other shrimp of any significance was *Crangon septemspinosa* (7.4%). *Dichelopandalus leptocerus* was also important in Southern New England and Georges Bank (8.6 and 1.8%, respectively), as were the euphausiids, *Meganyc-*

Table 4.—Geographic breakdown of food of the silver hake, *Merluccius bilinearis,* in the northwest Atlantic. Data are expressed as percentage weight, for fish collected during the spring and autumn bottom trawl survey cruises 1969-72. (+ indicates present but <0.1%.)

Prey	Middle Atlantic	Southern New England	Georges Bank	Gulf of Maine	Western Nova Scotia
POLYCHAETA	+	*1.1*	+	+	+
Nereidiformia	–	1.0	–	+	–
Terebelliformia	–	–	–	–	–
Sabelliformia	–	–	–	–	–
Other Polychaeta	+	0.1	+	+	+
CRUSTACEA	*27.7*	*33.6*	*20.4*	*21.5*	*33.8*
Amphipoda	1.0	1.3	0.1	+	+
Mysidacea	0.2	0.7	–	0.2	0.1
Euphausiacea	7.0	10.8	13.1	12.5	28.4
Pandalidae	8.5	15.7	2.6	1.7	0.4
Crangonidae	7.5	1.1	2.0	0.1	–
Axiidae	+	–	–	–	–
Paguridae	–	–	–	–	–
Majidae	–	–	–	–	–
Cancridae	0.1	–	+	0.1	–
Other Decapoda	0.7	1.3	0.7	4.8	0.2
Other Crustacea	2.7	2.7	1.9	2.1	4.7
MOLLUSCA	*13.6*	*0.8*	*0.6*	*1.3*	–
Gastropoda	+	–	–	–	–
Pelecypoda	+	–	–	+	–
Cephalopoda	13.6	0.8	0.6	1.3	–
Other Mollusca	+	–	–	–	–
ECHINODERMATA	–	–	+	–	–
Echinoidea	–	–	–	–	–
Ophiuroidea	–	–	+	–	–
Other Echinodermata	–	–	+	–	–
PISCES	*53.7*	*61.7*	*78.2*	*76.1*	*65.1*
Clupeidae	–	–	–	32.5	–
Gadidae	13.5	12.6	+	1.4	51.2
Scombridae	–	31.7	–	28.0	–
Scorpaenidae	–	–	–	–	–
Bothidae	–	–	–	–	–
Pleuronectidae	0.7	–	–	–	–
Other Pisces	39.5	17.4	78.2	14.2	13.9
Other groups	*0.1*	*0.2*	+	–	+
Animal remains	*4.9*	*2.6*	*0.8*	*1.1*	*1.1*
Sand and rock	+	+	+	+	+
Number of stomachs	465	704	248	453	282
Percentage of empty stomachs	34.6	35.8	24.6	30.7	33.3
Mean weight per stomach (g)	1.1	1.5	4.3	5.2	1.0
Mean predator fork length (cm)	26.7	27.5	29.9	27.1	27.7
Number of sampling stations	54	62	31	51	24

tiphanes (5.4 and 9.6%, respectively). In the Gulf of Maine, *Meganyctiphanes* was again the major crustacean prey (8.0%). The shrimp *Pasiphaea* (4.4%) replaced the pandalids, but *Dichelopandalus* (0.5%) and *Pandalus borealis* (0.3%) were still eaten in small quantities. In Western Nova Scotia euphausiids (28.4%), especially *Meganyctiphanes* (13.4%), were the only crustaceans of any significance.

The Mollusca were the only other taxonomic grouping to warrant discussion and here only in the Middle Atlantic. Cephalopods accounted for 13.6% of the diet with *Loligo* (8.3%) and *Rossia* (1.2%) being the two genera identified.

White hake, *Urophycis tenuis*.—White hake fed heavily on fish (Table 5). In Southern New England, silver hake (18.1%) and Atlantic mackerel (16.6%), were the most important prey, but "Other Pisces," such as the butterfish (2.8%) and wrymouth (1.7%), were also identified in the stomach contents. White hake taken fr Georges Bank were also found to prey on silver ha (6.0%), but other gadids, such as red hake (7.7%), haddock (3.8%), and to a lesser degree, longfin hake (0.3%), were important. Clupeids represented almost half t fish eaten (27.7%), and of these almost half (12.1%) w identified as Atlantic herring. The Clupeidae also contributed heavily to the diet of white hake in the Gulf of Maine (17.5%) and at least part of the remains w identified as Atlantic herring (6.6%). Atlantic macke (9.6%) also accounted for some of the prey as did a number of fish in the "Other Pisces" category (47.2%). Some of these other fish were *Argentina silus* (16.6 the wrymouth (1.1%); pearlsides (0.1%); and the s lance, *Ammodytes* (0.1%). In Western Nova Scotia, Atlantic cod (2.2%), longfin hake (1.3%), and white h (0.4%) contributed to the gadid prey. The redfish (4.7

.—Geographic breakdown of food of the white hake, *Uro-* *enuis*, in the northwest Atlantic. Data are expressed as per- ight, for fish collected during the spring and autumn vl survey cruises 1969-72. (Middle Atlantic = no samples; present but <0.1%.)

ey	Southern New England	Georges Bank	Gulf of Maine	Western Nova Scotia
HAETA	*0.1*	*0.1*	*0.1*	*0.3*
diformia	+	+	0.1	0.1
ormia	–	–	–	–
mia	–	–	–	–
ychaeta	0.1	0.1	+	0.2
ACEA	*3.7*	*29.4*	*21.1*	*10.4*
ipoda	0.3	0.1	+	0.1
a	–	–	+	+
acea	–	2.3	6.4	2.9
alidae	0.5	21.7	10.7	4.3
gonidae	0.3	1.1	0.1	0.4
	0.2	0.1	+	0.1
	–	0.4	–	+
	–	–	–	–
ridae	1.8	0.4	–	–
Decapoda	0.6	1.9	3.0	1.9
stacea	+	1.4	0.9	0.7
A	*11.6*	*3.8*	*0.2*	*0.4*
opoda	+	+	+	–
ypoda	–	+	+	–
alopoda	11.6	3.5	0.2	0.4
llusca	–	0.3	–	+
ERMATA	–	–	+	–
noidea	–	–	–	–
uroidea	–	–	+	–
r Echinodermata	–	–	–	–
	83.3	*62.5*	*76.5*	*86.5*
	–	27.6	17.5	0.8
dae	18.1	17.8	1.1	25.7
mbridae	16.6	–	9.6	–
dae	–	–	1.1	4.7
	–	–	–	–
onectidae	–	–	–	–
r Pisces	48.6	17.1	47.2	55.3
roups	*0.1*	+	*0.1*	+
ains	*1.2*	*4.0*	*2.0*	*2.3*
ck	–	*0.2*	+	*0.1*
r of stomachs	95	173	475	169
tage of empty	26.3	23.1	27.4	13.4
t per ach (g)	22.5	10.0	18.5	22.6
redator fork h)	48.3	45.3	46.5	43.7
ampling	24	38	74	41

Table 6.—Geographic breakdown of food of the offshore hake, *Merluccius albidus*, in the northwest Atlantic. Data are expressed as percentage weight, for fish collected during the spring and autumn bottom trawl survey cruises 1969-72. (Gulf of Maine and Western Nova Scotia = no samples; + indicates present but <0.1%.)

Prey	Middle Atlantic	Southern New England	Georges Bank
POLYCHAETA	–	–	–
Nereidiformia	–	–	–
Terebelliformia	–	–	–
Sabelliformia	–	–	–
Other Polychaeta	–	–	–
CRUSTACEA	*100.0*	*3.2*	*14.0*
Amphipoda	–	–	–
Mysidacea	–	–	–
Euphausiacea	62.5	0.8	1.5
Pandalidae	–	1.6	6.4
Crangonidae	–	–	–
Axiidae	–	–	–
Paguridae	–	–	–
Majidae	–	–	–
Cancridae	–	–	–
Other Decapoda	37.5	0.8	6.1
Other Crustacea	–	–	–
MOLLUSCA	–	–	5.1
Gastropoda	–	–	–
Pelecypoda	–	–	–
Cephalopoda	–	–	5.1
Other Mollusca	–	–	–
ECHINODERMATA	–	–	–
Echinoidea	–	–	–
Ophiuroidea	–	–	–
Other Echinodermata	–	–	–
PISCES	–	*96.7*	*80.4*
Clupeidae	–	–	–
Gadidae	–	73.8	–
Scombridae	–	–	–
Scorpaenidae	–	–	–
Bothidae	–	–	–
Pleuronectidae	–	–	–
Other Pisces	–	22.9	80.4
Other groups	–	+	–
Animal remains	–	*0.1*	*0.5*
Sand and rock	–	–	–
Number of stomachs	4	46	23
Percentage of empty stomachs	25.0	58.7	60.9
Mean weight per stomach (g)	0.1	3.1	1.4
Mean predator fork length (cm)	31.3	30.9	37.1
Number of sampling stations	2	9	3

e (2.9%), and longhorn sculpin (0.2%), are most er fish that were identified.

stacea was generally the second most important or[illegible]c grouping except in Southern New England phalopods (11.6%) such as *Loligo* (6.5%) were . In the Gulf of Maine and on Georges Bank species of pandalid shrimp were eaten, *Dichelo*-[illegible] *leptocerus* (0.1% in the Gulf of Maine and 3.5% s Bank), *Pandalus borealis* (3.9% in the Gulf of and 0.4% on Georges Bank), and *P. montagui* in the Gulf of Maine and 0.2% on Georges Bank). n Nova Scotia *P. propinquus* (0.2%) was also ut *P. borealis* was not. The only other crustaceans of note were euphausiids, and these primarily in the Gulf of Maine, where *Meganyctiphanes* (3.5%) was the most important species.

Offshore hake, *Merluccius albidus*.—Stomachs were collected from offshore hake in three of the five geographic areas (Table 6). In the Middle Atlantic, data were collected from only four fish, and therefore a discussion of the food in this area is of little value. Suffice it to say that the two species of Crustacea eaten, *Meganyctiphanes norvegica* and *Pasiphaea* sp., were also preyed upon in the other geographic areas. In Southern New England and on Georges Bank, the composition of the diet was very similar. In both areas fish was the major prey group (96.7% in Southern New England and 80.4% on Georges Bank); however, the particular species of fish could not be identified. Crustaceans were of secondary importance, with *Dichelopandalus leptocerus* (1.5% in Southern New England and 6.4% on Georges Bank) being the main prey item within this group.

Cusk, *Brosme brosme*.—The areal breakdown of food for cusk (Table 7) differs significantly from the summary (Table 1) which combines all areas into a single group. This is primarily due to the heavy predation on fish in Western Nova Scotia (98.2% of the diet). In the three other areas where cusk were collected the major prey was either crustaceans or echinoderms. On Georges Bank only four fish were examined and, of the two which had food in their stomachs, the prey was either stars (80.0%) or the toad crab, *Hyas coarctatus* (2 In Southern New England very few fish were e The total quantity of prey was extremely small sisted exclusively of amphipods, Aoridae (57.1% Gammaridae (42.9%). The largest sample of cusk from the Gulf of Maine, and here the primary Crustacea (90.6%). Of the decapods that could tified, the three pandalids, *Pandalus borealis* (1 *Dichelopandalus leptocerus* (3.5%), and *P. pr* (0.5%), together with some penaeid shrimp (6. the most important. However, small qua *Meganyctiphanes norvegica* (1.7%) were also fou the stomach contents. The remainder of the die ed of fish (4.2%), and "Other Groups" such iopods (1.2%), and sand or animal remains (3.9%

Table 7.—Geographic breakdown of food of the cusk, *Brosme brosme*, in the northwest Atlantic. Data are expressed as percentage weight, for fish collected during the spring and autumn bottom trawl survey cruises 1969-72. (Middle Atlantic = no samples; + indicates present but <0.1%.)

Prey	Southern New England	Georges Bank	Gulf of Maine	Western Nova Scotia
POLYCHAETA	–	–	–	–
Nereidiformia	–	–	–	–
Terebelliformia	–	–	–	–
Sabelliformia	–	–	–	–
Other Polychaeta	–	–	–	–
CRUSTACEA	*100.0*	*20.0*	*90.6*	*1.4*
Amphipoda	100.0	–	–	–
Mysidacea	–	–	–	–
Euphausiacea	–	–	1.7	–
Pandalidae	–	–	21.0	–
Crangonidae	–	–	–	–
Axiidae	–	–	–	–
Paguridae	–	–	–	–
Majidae	–	20.0	–	–
Cancridae	–	–	–	–
Other Decapoda	–	–	55.5	1.1
Other Crustacea	–	–	12.4	0.3
MOLLUSCA	–	–	–	–
Gastropoda	–	–	–	–
Pelecypoda	–	–	–	–
Cephalopoda	–	–	–	–
Other Mollusca	–	–	–	–
ECHINODERMATA	–	*80.0*	–	–
Echinoidea	–	–	–	–
Ophiuroidea	–	80.0	–	–
Other Echinodermata	–	–	–	–
PISCES	–	–	*4.2*	*98.2*
Clupeidae	–	–	–	–
Gadidae	–	–	–	–
Scombridae	–	–	–	–
Scorpaenidae	–	–	–	–
Bothidae	–	–	–	–
Pleuronectidae	–	–	–	–
Other Pisces	–	–	4.2	98.2
Other groups	–	–	*1.3*	–
Animal remains	–	–	*3.1*	*0.4*
Sand and rock	–	–	*0.8*	–
Number of stomachs	6	4	51	11
Percentage of empty stomachs	33.3	50.0	78.4	81.8
Mean weight per stomach (g)	0.01	4.89	0.88	15.03
Mean predator fork length (cm)	25.5	57.3	64.8	60.5
Number of sampling stations	1	4	29	9

Red hake, *Urophycis chuss*.—In all five ge areas, at least half the red hake's diet was com crustaceans (Table 8). In the Middle Atlantic, m crabs of the genera *Munida* (16.9%) and *Munid* (3.3%) accounted for a large percentage of th ceans classified under "Other Decapoda." shrimp (15.7%) were the next most important prey with the majority of these identified as *Dichelopan* (9.1%). Of secondary importance were the uni amphipods (5.1%); the rock crab, *Cancer irroratu* the sand shrimp, *Crangon* (2.2%); and the is *Cirolina* (1.8%). In Southern New England the crab, *Munida* (12.9%), was again of primar tance, as was *Dichelopandalus* (5.6%). *Cancer* (1.6%) and *Crangon* (1.5%) were also preyed upon Georges Bank the hermit crab, *Pagurus* (10.6%) sand shrimp, *Crangon* (20.6%), were major pr *Cancer* crabs (8.7%) and pandalid shrimp, *Dic* *dalus* (6.1%), also contributed significantly to the Euphausiids (18.7%), some of which could be i as *Meganyctiphanes* (5.6%); the pandalid *Dichelopandalus* (11.6%); and the crab *Cancer* (11 were of major importance in the Gulf of Maine, whi pandalids, *Dichelopandalus leptocerus* (30.9%) *dalus montagui* (40.3%), were the primary Western Nova Scotia.

In three of the geographic areas, Pisces followe Crustacea as a major prey category. Many of eaten in the Middle Atlantic could not be id However, of those identified one of the "Other Pi was the snake eel (5.9%), and the pleuronectid wa winter flounder (0.1%). Red hake were cannib Southern New England (0.3%) but also ate oth such as the silver hake (0.3%). The wrymouth (1 Gulf Stream flounder (0.9%), and the Atlantic (0.6%) made up a small percentage of the c eaten. On Georges Bank clupeids (3.5%) an Pisces" (1.8%) accounted for all the fish prey. Fis mains (23.9%) from the stomachs of red hake the Gulf of Maine could not be identified.

Table 8.—Geographic breakdown of food of the red hake, *Urophycis chuss*, in the northwest Atlantic. Data are expressed as percentage weight, for fish collected during the spring and autumn bottom trawl survey cruises 1969-72. (+ indicates present but <0.1%.)

Prey	Middle Atlantic	Southern New England	Georges Bank	Gulf of Maine	Western Nova Scotia
POLYCHAETA	*1.4*	*3.3*	*3.0*	*2.9*	*2.4*
Nereidiformia	0.1	1.7	1.1	0.6	0.4
Terebelliformia	–	–	0.2	–	–
Sabelliformia	–	0.2	+	–	–
Other Polychaeta	1.3	1.4	1.7	2.3	2.0
CRUSTACEA	*52.2*	*50.8*	*57.2*	*64.7*	*88.5*
Amphipoda	5.5	9.6	4.3	1.8	1.9
Mysidacea	0.1	+	+	0.6	0.2
Euphausiacea	+	1.8	2.0	18.7	2.3
Pandalidae	15.7	9.4	7.7	19.7	71.2
Crangonidae	2.2	1.5	10.6	0.6	1.9
Axiidae	–	2.9	1.9	–	–
Paguridae	0.5	1.3	10.6	2.3	3.2
Majidae	+	0.1	–	–	–
Cancridae	2.7	4.4	8.7	11.2	–
Other Decapoda	21.7	15.5	3.0	4.4	7.6
Other Crustacea	3.8	4.3	8.4	5.4	0.2
MOLLUSCA	*0.3*	*5.4*	*17.7*	*3.8*	–
Gastropoda	0.2	0.1	17.4	3.8	–
Pelecypoda	0.1	+	–	–	–
Cephalopoda	–	2.2	–	–	–
Other Mollusca	+	3.1	0.3	–	–
ECHINODERMATA	*0.1*	*0.6*	*0.2*	*2.0*	–
Echinoidea	–	0.1	0.2	–	–
Ophiuroidea	–	–	–	–	–
Other Echinodermata	0.1	0.5	+	2.0	–
PISCES	*38.5*	*28.2*	*5.3*	*23.9*	*0.6*
Clupeidae	–	–	3.5	–	–
Gadidae	–	0.7	–	–	–
Scombridae	–	0.6	–	–	–
Scorpaenidae	–	–	–	–	–
Bothidae	–	0.9	–	–	–
Pleuronectidae	0.1	–	–	–	–
Other Pisces	38.4	26.0	1.8	23.9	0.6
Other groups	+	*1.2*	*0.2*	*0.1*	*5.4*
Animal remains	*7.2*	*10.3*	*16.2*	*2.5*	*2.9*
Sand and rock	*0.3*	*0.2*	*0.2*	*0.1*	*0.2*
Number of stomachs	206	607	208	72	17
Percentage of empty stomachs	16.4	13.3	21.6	19.4	11.8
Mean weight per stomach (g)	1.8	2.4	1.9	2.9	2.6
Mean predator fork length (cm)	29.3	29.6	33.1	34.3	32.6
Number of sampling stations	25	71	30	20	8

e only other taxon that was of any significance, and on Georges Bank, was the Mollusca of the class da (17.4%).

otted hake, *Urophycis regius*.—The areal break- ood of the spotted hake is limited to the Middle and Southern New England, since no stomachs collected in the Gulf of Maine and Western Nova nd only four fish were analyzed from Georges able 9). A comparison between the two areas hat the foods were reasonably similar, the major cence being due to the importance of cephalopods especially *Loligo* (6.8%), in the Middle Atlan-

ustaceans were a major prey category. In both the lle Atlantic and Southern New England the "Other a" was the largest grouping consisting mostly of d crabs. In the Middle Atlantic, *Munida* (9.4%), both *M. iris* (7.4%) and *M. valida* (1.7%), together with *Munidopsis* (2.8%), were present in the stomach contents, but in Southern New England the species were restricted to *M. iris* (11.3%) and *M. valida* (9.2%). Interestingly, hyperiid amphipods were important, making up 3.4% of the diet in the Middle Atlantic and 6.1% in Southern New England. The rock crab, *Cancer irroratus* (6.7%), composed a significant part of the prey in the Middle Atlantic. Other crustaceans of secondary importance were *Crangon* (4.8% in the Middle Atlantic and 2.6% in Southern New England), *Dichelopandalus* (3.6% in the Middle Atlantic and 4.0% in Southern New England), and the isopods (3.1% in the Middle Atlantic only), such as *Cirolina polita* (0.7%), which are included under "Other Crustacea."

"Pisces" was the last major grouping. In the Middle Atlantic, red hake (3.4%) and silver hake (3.3%); the bothid, *Citharichthys arctifrons* (1.7%); the pleuro-

Table 9.—Geographic breakdown of food of the spotted hake, *Urophycis regius,* in the northwest Atlantic. Data are expressed as percentage weight, for fish collected during the spring and autumn bottom trawl survey cruises 1969-72. (Gulf of Maine and Western Nova Scotia = no samples; + indicates present but <0.1%.)

Prey	Middle Atlantic		Southern New England		Georges Bank	
POLYCHAETA	*0.4*		*0.6*		–	
Nereidiformia		0.1		0.1		–
Terebelliformia		–		–		–
Sabelliformia		–		–		–
Other Polychaeta		0.3		0.5		–
CRUSTACEA	*48.6*		*46.8*		*6.8*	
Amphipoda		8.0		6.2		2.9
Mysidacea		+		–		–
Euphausiacea		+		0.1		–
Pandalidae		3.8		4.3		–
Crangonidae		5.0		2.6		1.2
Axiidae		–		0.1		–
Paguridae		0.1		0.1		–
Majidae		+		–		–
Cancridae		10.3		1.1		–
Other Decapoda		14.5		31.9		0.3
Other Crustacea		6.9		0.4		2.4
MOLLUSCA	*16.6*		*1.1*		*71.6*	
Gastropoda		0.1		–		–
Pelecypoda		0.4		–		–
Cephalopoda		16.1		1.0		71.6
Other Mollusca		+		0.1		–
ECHINODERMATA	–		+		–	
Echinoidea		–		–		–
Ophiuroidea		–		–		–
Other Echinodermata		–		+		–
PISCES	*28.5*		*45.1*		*0.3*	
Clupeidae		–		–		–
Gadidae		6.8		0.3		–
Scombridae		–		9.1		–
Scorpaenidae		–		–		–
Bothidae		1.7		1.9		–
Pleuronectidae		0.8		0.8		–
Other Pisces		19.2		33.0		0.3
Other groups	+		*0.1*		+	
Animal remains	*5.7*		*5.8*		*21.3*	
Sand and rock	*0.2*		*0.5*		+	
Number of stomachs	689		183		4	
Percentage of empty stomachs	10.5		31.0		25.0	
Mean weight per stomach (g)	0.8		1.9		2.8	
Mean predator fork length (cm)	18.2		26.2		24.1	
Number of sampling stations	45		17		2	

nectid, *Limanda ferruginea* (0.8%); and "Other Pisces" (19.2%) such as the snake eel (0.2%), and lanternfish (family Myctophidae) (3.9%), constituted the fish prey. In Southern New England the fawn cusk-eel (1.1%) and some unidentified cusk eels (10.8%), together with Atlantic mackerel (9.1%), the Gulf Stream flounder (1.9%), and silver hake (1.1%), represented a large part of the fish consumed.

Haddock, *Melanogrammus aeglefinus*.—Few haddock were collected in the Middle Atlantic and Southern New England and therefore the following discussion is limited primarily to the three other geographic areas (Table 10).

Fish accounted for more than one-fourth (28.4%) of the haddock's diet on Georges Bank whereas fish were reasonably insignificant in all the other areas. This sh
food was not, however, due to a change in fee
strategy but rather was entirely due to the co
of herring eggs. This implies that haddock pr
on herring spawn when it is available. Polychaetes
also more important prey on Georges Bank (23.5%)
in the other areas. The "Other Polychaeta"
contributed the largest percentage (18.3%) with *An*
trypane aulogaster (8.3%) being the most impo
animal. *Laonice* (0.1%), *Ophelia* (<0.1%), *Sc*
(<0.1%), and *Sternaspis* (0.1%) were other p
identified in the stomach contents. None of the
belliformia (2.1%) could be identified below sub
and *Chone infundibuliformis* (0.3%) was
Sabelliformia (2.1%) identified to species. The
group that was of any significance was the crustac
(16.0%). Amphipods (7.1%) made up the largest po
but the individual species of amphipods u
counted for <0.1%. As a group the gammar
pods were the most important, with species such as
ciola irrorata (<0.1%), *Casco bigelowi* (<0.1%), *An*
sp. (0.1%), *Leptocerus pinguis* (0.1%), and *P*
(<0.1%) having been found in the haddock
Echinoderms (7.8%) and molluscs (3.8%) were the
important prey groups for Georges Bank haddock. B
stars, such as *Ophiopholis aculeata* (2.4%),
most important echinoderms, while pelecy
Astarte (0.2%) and *Pecten* (0.1%) were the more in
tant molluscs that could be identified. Sand
(15.3%) were more prevalent in the haddock
collected on Georges Bank than elsewhere, possibl
cause polychaetes and pelecypods accounted for a l
percentage of the diet here than in the other

The haddock's food in the Gulf of Maine and
Nova Scotia were quite different from those in the
three geographic areas, but within these two
prey was similar. For example, in both areas ha
consisted of echinoderms. Similarly, crustaceans
polychaetes contributed between 10 and 15% of the
and molluscs between 1 and 3%. Brittle stars
main food item, with *Ophiura* (16.2%) being o
importance in the Gulf of Maine. However, *Amp*
(0.8%), *Ophiopholis* (0.4%), and *Ophiacantha bide*
(<0.1%), together with unidentified ophiuroi
(20.5%), are also included in this prey group. In
Nova Scotia three ophiuroids were eaten, *Ophiop*
(13.0%), *Ophiura* (8.2%), and *Amphiopolis* (0
together with some unidentifiable ophiuroid
(13.0%). In the Gulf of Maine 15.2% of the
crustaceans. The "Other Decapoda" was the la
group (5.9%) primarily because of the shrimp *Pasi*
(4.9%). The shrimp *Pandalus* (2.0%) was of s
importance as were euphausiids (1.9%) and g
amphipods (1.8%). Gammarid amphipods (3.4%) as
as the caprellid; *Aeginina longicornis* (0.3%),
main crustacean prey in Western Nova Scotia,
Axiide, both *Axius* (1.8%) and *Calocaris* (0.5%), we
secondary importance. Polychaetes were the only
group accounting for much of the diet. The maj
not identified below the order level, but in th

Table 10.—Geographic breakdown of food of haddock, *Melanogrammus aeglefinus*, in the northwest Atlantic. Data are expressed as percentage weight, for fish collected during the spring and autumn bottom trawl survey cruises 1969-72. (+ indicates present but <0.1%.)

Prey	Middle Atlantic	Southern New England	Georges Bank	Gulf of Maine	Western Nova Scotia
POLYCHAETA	*14.3*	*4.5*	*23.5*	*14.7*	*11.8*
Nereidiformia	13.4	2.5	1.0	3.0	2.7
Terebelliformia	–	–	2.1	+	1.9
Sabelliformia	–	–	2.1	0.5	0.8
Other Polychaeta	0.9	2.0	18.3	11.2	6.4
CRUSTACEA	*2.2*	*82.0*	*16.0*	*15.2*	*14.4*
Amphipoda	0.6	75.3	7.1	2.2	5.0
Mysidacea	–	–	0.1	–	+
Euphausiacea	–	–	3.7	2.0	1.7
Pandalidae	–	0.7	1.1	2.9	1.0
Crangonidae	0.3	0.5	0.2	–	0.1
Axiidae	–	–	0.2	0.2	2.3
Paguridae	–	0.9	0.2	0.1	0.8
Majidae	–	0.6	0.1	0.5	0.4
Cancridae	–	0.2	0.2	–	–
Other Decapoda	–	1.0	0.2	5.9	1.7
Other Crustacea	1.3	2.8	2.9	1.4	1.4
MOLLUSCA	*0.4*	*0.7*	*3.8*	*1.6*	*3.0*
Gastropoda	0.4	+	0.2	0.5	0.3
Pelecypoda	–	0.7	3.2	0.9	1.9
Cephalopoda	–	+	0.1	–	0.5
Other Mollusca	–	–	0.3	0.2	0.3
ECHINODERMATA	–	*1.4*	*7.8*	*51.9*	*49.0*
Echinoidea	–	1.2	1.5	10.6	9.0
Ophiuroidea	–	+	6.0	38.0	34.5
Other Echinodermata	–	0.2	0.3	3.3	5.5
PISCES	–	+	*28.4*	*2.2*	*3.8*
Clupeidae	–	–	28.3	–	–
Gadidae	–	–	–	–	0.8
Scombridae	–	–	–	–	–
Scorpaenidae	–	–	–	–	–
Bothidae	–	–	–	–	–
Pleuronectidae	–	–	+	–	–
Other Pisces	–	+	0.1	2.2	3.0
Other groups	*1.1*	*0.1*	*0.3*	*0.6*	*2.0*
Animal remains	–	*8.3*	*4.9*	*11.2*	*13.0*
Sand and rock	*82.0*	*3.0*	*15.3*	*2.6*	*3.0*
Number of stomachs	10	27	352	232	510
Percentage of empty stomachs	0.0	11.1	4.3	5.6	10.0
Mean weight per stomach (g)	3.2	4.1	10.0	6.6	4.9
Mean predator fork length (cm)	20.1	54.8	46.7	56.3	43.4
Number of sampling stations	1	5	45	47	56

ome of the more common were *Sabella* (0.4%), *pennata* (0.2%), *Nephtys* (0.2%), *Goniada* and *Lumbrineris* (0.1%). In Western Nova Scotia y of polychaetes were identified in the stomach but the only genera contributing >0.1% to the e *Cistenides* (0.5%), *Aphrodita* (0.8%), and (0.4%).

h hake, *Phycis chesteri*.—Although longfin collected in all five geographic areas, a discus- he areal breakdown of its prey is of little value. were collected and, on Georges Bank, where the mple was taken, over half the stomachs were fectively leaving a maximum of 26 fish from 6 to evaluate the food in any one region. Never- all areas, crustaceans were the major prey, uphausiid, *Meganyctiphanes norvegica*, being important.

Fourbeard rockling, *Enchelyopus cimbrius*.—Fourbeard rockling were collected for stomach contents analysis in three of the five geographic areas. Only on Georges Bank, however, was the total weight of the prey (12.42 g) and sample size (n = 27) sufficiently large to warrant any discussion. On Georges Bank crustaceans were the major prey, accounting for 59.3% of the diet. The two most important crustaceans were *Crangon septemspinosa* (46.3%) and *Dichelopandalus leptocerus* (11.2%). The other taxonomic grouping of importance was the Polychaeta (13.6%), and here the only identification to the genus level was *Ammotrypane* (3.9%).

Marlin-spike, *Nezumia bairdi*.—Marlin-spike were collected in three of the geographic areas, Southern New England, Gulf of Maine, and Western Nova Scotia, but in very small numbers. Due to the small sample size, both in the number of fish examined and the total weight of prey, a meaningful discussion of areal differences in food is unwarranted. Table 2 adequately summarizes the available information.

Longnose grenadier, *Coelorhynchus carminatus*.—As has been described for the marlin-spike, a meaningful discussion of the areal differences in food is not justifiable because of the small number of fish examined and the small quantity of prey in the stomachs.

Fawn cusk-eel, *Lepophidium cervinum*.—Fawn cusk-eel were collected in significant numbers in the Middle Atlantic and Southern New England but the total quantity of prey in the stomachs amounted to only 3.27 g. An areal breakdown of their food is therefore of little value, especially since almost 1 g of the total weight was due to a heavy infestation of parasitic nematodes (37.1%) in the fish collected in the Middle Atlantic. summary of the food see Table 2.

Ocean pout, *Macrozoarces americanus*.— pout were collected in all areas but were most abu in Southern New England and on Georges Ba 11). In these two areas the major prey was ech with the sand dollar being the single most impo species (54.4% in Southern New England and 61. Georges Bank). In Southern New England, c (22.0%) and polychaetes (7.8%) made up m remainder of the prey. Amphipods (13.1%), such a *ciola* sp. (1.0%) and *Leptocerus pinguis* (1.2%). important, as were the rock crabs (5.4%), p *Cancer irroratus* (2.0%). The majority of the prey was identified as *Aphrodita* (7.4%). On Ge Bank, crustaceans (4.3%) were of little signifi

Table 11.—Geographic breakdown of food of ocean pout, *Macrozoarces americanus*, in the northwest Atlantic. Data are expressed as percentage weight, for fish collected during the spring and autumn bottom trawl survey cruises 1969-72. (+ indicates present but <0.1%.)

Prey	Middle Atlantic	Southern New England	Georges Bank	Gulf of Maine	Western Nova Scotia
POLYCHAETA	–	*7.8*	*0.5*	*0.3*	–
Nereidiformia	–	7.7	+	–	–
Terebelliformia	–	–	+	+	–
Sabelliformia	–	–	–	–	–
Other Polychaeta	–	0.1	0.5	0.3	–
CRUSTACEA	*9.4*	*22.0*	*4.3*	*3.5*	+
Amphipoda	0.2	13.1	0.7	2.0	–
Mysidacea	–	–	–	–	–
Euphausiacea	–	–	–	–	–
Pandalidae	–	+	+	–	–
Crangonidae	–	+	+	0.2	–
Axiidae	–	–	–	–	–
Paguridae	0.3	0.1	0.8	0.3	–
Majidae	–	–	0.7	–	–
Cancridae	5.7	5.4	1.3	0.1	–
Other Decapoda	–	1.3	0.7	–	–
Other Crustacea	3.2	2.1	0.1	0.9	+
MOLLUSCA	–	*1.6*	*6.1*	*4.1*	–
Gastropoda	–	0.9	0.1	2.0	–
Pelecypoda	–	0.6	5.9	2.1	–
Cephalopoda	–	–	–	–	–
Other Mollusca	–	0.1	0.1	–	–
ECHINODERMATA	*86.3*	*63.9*	*81.1*	*37.2*	*99.3*
Echinoidea	86.3	63.9	71.5	25.3	–
Ophiuroidea	–	+	9.6	6.2	99.3
Other Echinodermata	–	–	–	5.7	–
PISCES	*0.5*	*0.1*	+	*0.5*	+
Clupeidae	–	–	–	–	–
Gadidae	–	–	–	–	–
Scombridae	–	–	–	–	–
Scorpaenidae	–	–	–	–	–
Bothidae	–	–	–	–	–
Pleuronectidae	–	–	–	–	–
Other Pisces	0.5	0.1	+	0.5	+
Other groups	*0.2*	*0.3*	*1.9*	*18.5*	–
Animal remains	*1.8*	*2.5*	*5.4*	*2.5*	–
Sand and rock	*1.8*	*1.8*	*0.7*	*33.4*	*0.7*
Number of stomachs	20	207	110	34	6
Percentage of empty stomachs	0.0	22.5	32.7	26.5	66.7
Mean weight per stomach (g)	6.6	5.0	10.6	6.4	0.5
Mean predator fork length (cm)	44.7	45.2	56.5	36.6	32.4
Number of sampling stations	4	23	31	4	3

olds (9.6%), such as *Ophiopholis* (1.1%), and the pod, *Pecten* (4.5%), formed the remaining bulk of

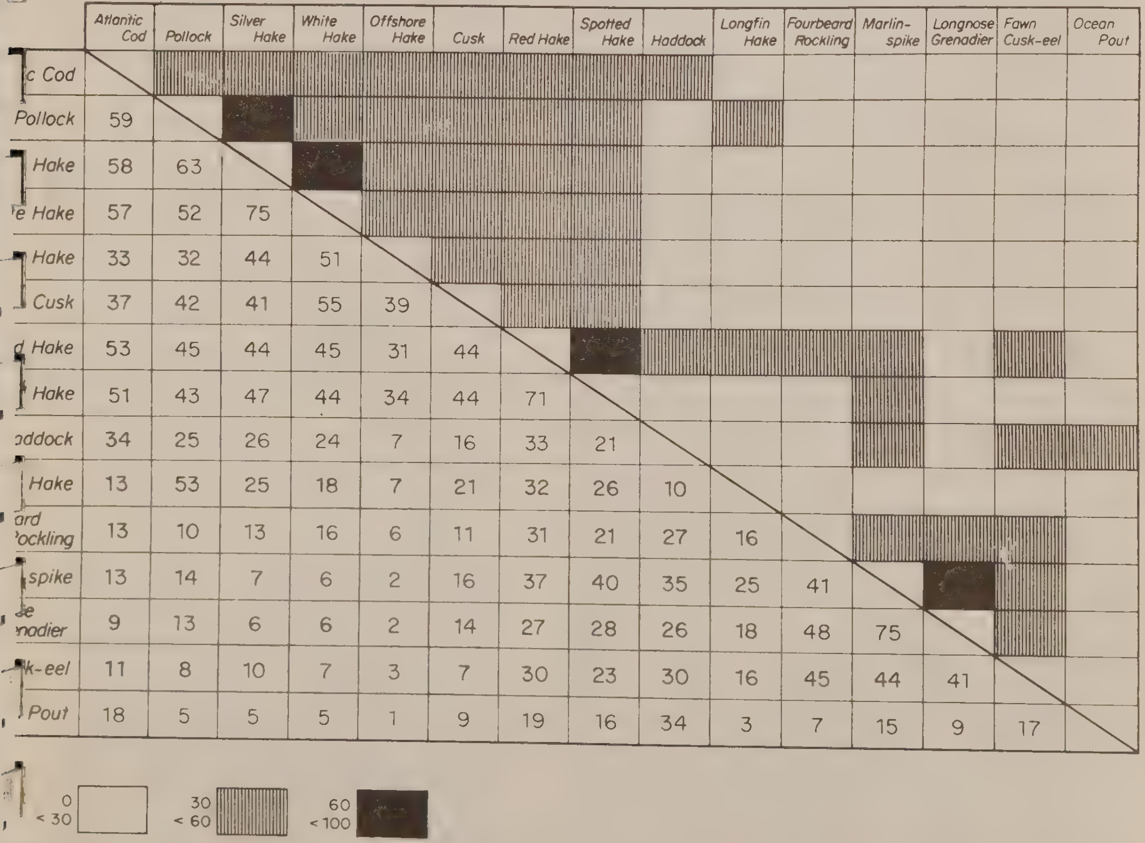
In the Middle Atlantic few ocean pout were col- out as on Georges Bank and in Southern New nd, the single major prey species was the sand dol- 6.3%). In the Gulf of Maine echinoderms were tly less important although *E. parma* still ac- for 24.8% of the prey. "Other Groups" was also tant and the single contributor to this category was icate, *Cnemidocarpa mollis* (18.5%). Sand and .4%) made up a large part of the weight of the contents.

Overlap

percentage similarity values (Fig. 3) calculated data in Table 2 range from 1 to a maximum of ler to facilitate the comparison between species, ity values have been grouped into three cate- representing low (0 to <30%), intermediate (30 to and high (60 to 100%) levels of dietary overlap. gly, it is obvious that the greatest similarity in ists between the silver and white hake (75%), the spike and longnose grenadier (75%), the red and spotted hake (71%), and the pollock and silver hake (63%).

The diets of Atlantic cod, pollock, silver hake, white hake, offshore hake, cusk, red hake, and spotted hake are reasonably similar. Most of these fish populations are primarily piscivorous, which accounts for the observed intermediate and high levels of dietary overlap. The red and spotted hake, however, qualify as "mixed feeders" preying on both fish and invertebrates. In contrast to the eight predators listed above, the remaining seven species: haddock, longfin hake, fourbeard rockling, marlin-spike, longnose grenadier, fawn cusk-eel, and ocean pout, prey almost exclusively on invertebrates. Of these fish only the haddock preyed extensively on other fish and this was predation on herring eggs rather than on juvenile or adult fishes. The lack of similarity between the diet of the invertebrate feeders is in part due to the more numerous categories of potential prey. In some instances, such as for the marlin-spike, longnose grenadier, and fourbeard rockling, estimates of diet similarly are of limited value because of the small number of fish examined and/or the small amount of prey found in the stomachs.

The percentage similarity in diet has also been calculated for each fish in the five individual geographic



	Atlantic Cod	Pollock	Silver Hake	White Hake	Offshore Hake	Cusk	Red Hake	Spotted Hake	Haddock	Longfin Hake	Fourbeard Rockling	Marlin-spike	Longnose Grenadier	Fawn Cusk-eel	Ocean Pout
c Cod		▨	▨	▨	▨	▨	▨	▨	▨						
Pollock	59		■	▨	▨	▨	▨	▨		▨					
Hake	58	63		■	▨	▨	▨	▨							
e Hake	57	52	75		▨	▨	▨	▨							
Hake	33	32	44	51		▨	▨	▨							
Cusk	37	42	41	55	39		▨	▨							
d Hake	53	45	44	45	31	44		■	▨	▨	▨	▨		▨	
Hake	51	43	47	44	34	44	71					▨			
addock	34	25	26	24	7	16	33	21				▨		▨	▨
Hake	13	53	25	18	7	21	32	26	10						
ard ockling	13	10	13	16	6	11	31	21	27	16		▨	▨	▨	
spike	13	14	7	6	2	16	37	40	35	25	41		■	▨	
e nadier	9	13	6	6	2	14	27	28	26	18	48	75		▨	
k-eel	11	8	10	7	3	7	30	23	30	16	45	44	41		
Pout	18	5	5	5	1	9	19	16	34	3	7	15	9	17	

Percentage similarity between the diet of 15 species of gadiform fishes from the northwest Atlantic. For calculation methods, see text. Open boxes = 0 to <30%; ruled boxes = 30 to <60%; solid boxes = 60 to 100%.

areas. The 15 species of fish were not omnipresent and the data were only included in the calculations if 10 or more individuals of that particular species were collected in a geographic area for stomach contents analysis.

Only 6 of the 15 predators were collected in sufficiently large numbers in the Middle Atlantic to warrant an analysis of dietary overlap. Three of these six fish—silver, red, and spotted hake—showed intermediate levels of dietary overlap, while the similarity in diet for the haddock, fawn cusk-eel, and ocean pout was low.

In Southern New England 10 of the 15 predators were present. A high degree of similarity in diet occurred between the red and spotted hake. These two fish fed on both fish and invertebrates, and shared many of the same species as prey (Tables 8, 9). Intermediate levels of dietary overlap were generally found between the four piscivorous predators, Atlantic cod, silver hake, white hake, and offshore hake, and also between these same four fish and the red and spotted hake. The only other intermediate levels of overlap occurred between the fawn cusk-eel and the red hake and haddock. Little similarity was found between the diet of the haddock, longfin hake, fawn cusk-eel, ocean pout, and the other more piscivorous predators mentioned above.

For the fish taken on Georges Bank high levels of dietary overlap occurred between the offshore and silver hake and between the pollock and longfin hake. The high overlap between the pollock, which have normally been considered piscivorous, and the longfin hake, an invertebrate feeder, may be explained by the dependence on Crustacea as a major food source for Georges Bank pollock (Table 3). It should also be noted that the average length of pollock on Georges Bank was smaller than in the other geographic areas which might explain the reliance on crustaceans rather than fish. Intermediate levels of diet similarity were found for a number of fish. Most notable is the overlap between Atlantic cod and haddock which may be traced to the heavy predation on herring eggs by the Georges Bank haddock. Since Atlantic cod were preying on either juvenile or adult herring, this measure of overlap is somewhat misleading. Low levels of similarity were again observed between the invertebrate feeders.

In the Gulf of Maine high and intermediate levels of dietary overlap were found between the Atlantic cod, pollock, silver hake, white hake, and red hake, but little similarity was observed between the diet of these same predators and the haddock, longfin hake, fourbeard rockling, and ocean pout. The cusk showed an intermediate level of dietary overlap with the pollock, red hake, and fourbeard rockling while the diet of the ocean pout was found to have an intermediate degree of similarity with the haddock. All the remaining fish showed a low level of dietary overlap.

In Western Nova Scotia the highest level of dietary overlap was found between the Atlantic cod and white hake. Intermediate overlap was generally found between the diets of the Atlantic cod, pollock, silver hake, white hake, and cusk. Longfin hake also showed an intermediate level of overlap with the pollock, silver h
and marlin-spike. The last intermediate level occu
between the marlin-spike and haddock. Little
in diet was found for the other gadiform fish co
the Scotian Shelf.

DISCUSSION

Food

Atlantic cod.—Data on the diet of the At
occurring off the U.S. coast in the Gulf of Maine
been summarized by Bigelow and Schroeder (1953
also Wise 1961), but, surprisingly, there is li
information for the region of the present study (
dall 1898; Tyler 1972). The Canadian cod stocks i
Gulf of St. Lawrence and off Newfoundland have,
ever, been more thoroughly investigated (Po
Popova 1962; Templeman 1965; Kohler and
1969; Minet and Perodou 1978).

From some of the earliest studies it was conclude
Atlantic cod will eat almost any food available.
wide diversity in the species composition of t
rather simple picture of the cod's food habits ma
drawn from most of the available data. In gen
taceans and fish are the major prey, while t
percentage of the diet made up of each of these tw
onomic groups is determined by prey size and prey
ability. Small cod prey on small crustaceans, su
phipods and mysids. Slightly larger cod prey
decapod crabs and shrimp. The larger cod prey a
exclusively on fish. Our observations on the fo
Atlantic cod caught off the U.S. coast are in a
with this rather simplistic description. Althou
not separate the data into size classes, it can be seen
fish and crustaceans were the most important prey
gories (Table 1). We did not include the smaller
cm) in our data base, and the average length of
animals we analyzed was 54.7 cm (Table 1). C
approximately 50 cm FL (fork length) have previ
been shown to prey heavily on both fish and cr
(Powles 1958; Popova 1962; Rae 1968) so that
may be taken as confirmation that the diet of the
cod stocks is very similar to the other populati
have previously been investigated.

Pollock.—The diet of pollock was equally divide
tween fish and crustaceans (Table 1). Atlant
was the major species of fish preyed upon
euphausiid, *Meganyctiphanes norvegica*, was the
most important prey. The significance of euphausi
the diet of pollock had previously been noted b
(1898) who found that *Thysanopoda* were vir
exclusive prey for pollock taken off Eastport, Maine
elow and Schroeder (1953) included Kendall's obs
tions in their treatise on fishes in the Gulf of
also mentioned that young herring were an eq
portant prey. Steele (1963) and Dexter (1969) again
firmed the importance of euphausiids such as *M*
vegica as major prey for pollock in the Gulf

er, Steele also remarked that fish were eaten in n to euphausiids by the larger (75+ cm) pollock. n predator fork length for pollock taken in the Maine (Table 3) during the present study (66.4 as greater than for the fish caught on either s Bank (38.2 cm) or in Western Nova Scotia (44.6 ordingly, fish, especially Atlantic herring, were re important as prey for the Gulf of Maine pol- an in either of the other two areas. In European e food of pollock appears to be similar to that of erican counterparts as they have also been to prey heavily on euphausiids (Wagner 1959; va 1961; and see Nagabhushanam 1965 for a brief tabular form).

r hake.—Fish accounted for almost three-fourths t of silver hake, with crustaceans making up the g prey (Table 1). Fish had previously been d as the major prey of the silver hake by Bige- d Schroeder (1953). They described these pre- preying on herring or most any other smaller fish or even the young of almost any of the fish y found in the Gulf of Maine. For example, and Breder (1927) found 75 herring, 7.62 cm he stomach of a 59 cm silver hake. Bigelow and r (1953) also noted that silver hake ate squid if e while smaller hake fed on the shrimp *Pandalus*. and Fritz (1960) reported on the diet of silver llected in the northwest Atlantic. Expressing a as the frequency of occurrence of prey, they nd that fish predominated in the stomachs of the ilver hake while crustaceans, mostly euphau- re more common in the stomachs of the smaller re recently, Vinogradov (1972) examined a total 5 silver hake stomachs collected from fish caught rthwest Atlantic. He also found that the smaller yed on crustaceans, especially euphausiids, with o fish as the major prey for hake >40 cm FL. ingly, all of these authors have commented on ibalistic nature of silver hake which was again ed in this report, especially for fish taken in the Atlantic (Table 4).

hake.—The white hake and red hake resemble er closely and the landings of these hakes have en reported separately since 1944. Therefore, n the food habits of white hake alone are rela- e. Linton (1901) examined the stomachs of some ake but they were empty, and Hansen (1915) ome euphausiids, *Thysanoessa inermis*, in the s he examined. Bigelow and Schroeder (1953) the food of the two hakes together although they lly mention the occurrence of squid, crabs, sh, mackerel, and flounder in the stomachs of ite hake. Apart from the data given here (Table h identifies white hake as being primarily pisci- the only other recent reports discussing the food fish are by Tyler (1971, 1972) and Petrov (1973). 971) observed seasonal changes in the distri- nd the diet of fishes in Passamaquoddy Bay, New Brunswick, Canada. White hake were present in the bay during summer and autumn. For the smaller white hake (total length range 15-26 cm) Tyler identified mysids, amphipods, and euphausiids as principal prey while the larger fish (28-45 cm) preyed upon shrimp, euphausiids, and fish. The data reported here are generally for larger fish (average total = 46.4 cm FL, see Table 1) than those considered by Tyler and this may explain our observation that white hake are primarily piscivorous. Petrov (1973) collected food habits data for the years 1969, 1971, and 1972 in ICNAF (International Commission for the Northwest Atlantic Fisheries) Subarea 3 which is north of our study area, off the eastern coast of Canada. Petrov's data are based on a subsample of the entire population and, although based on frequency of occurrence, show very similar results to those reported here (Table 1). He found that fish predominated in the diet with crustaceans being of secondary importance.

Offshore hake.—Biological data on the offshore hake is rare, and information on its food has only just become available. Rohr and Gutherz (1977) described the offshore hake as an active predator, preying on crustaceans and fish including other offshore hake. Juveniles were found to prey heavily on shrimp while maturing adults fed on fish, shrimp, and squid. The primary prey of adults was fish, but they also preyed upon caridean shrimp and squid. The offshore hake examined during the course of the present study confirm the observations of Rohr and Gutherz. The hake we examined preyed heavily on fish but also consumed crustaceans (i.e., caridean shrimp and euphausiids) and squid (Table 1).

Cusk.—Cusk were identified as being primarily fish-eaters, although crustaceans and echinoderms were also important prey, but to a lesser extent (Table 1). The cusk's piscivorous habits may be accounted for because of its heavy reliance on fish as prey in Western Nova Scotia (Table 7). In contrast, crustaceans made up 90% of the diet in the Gulf of Maine (Table 7), but because of the total weight of fish prey when all five geographic areas are combined, crustaceans are of secondary importance (Table 1). Little comparative data exist on the food of this animal, but it has been reported that crabs and occasionally molluscs were found in the stomachs of several cusk caught on Platt's Bank in the Gulf of Maine in 1924 (Bigelow and Schroeder 1953). Leim and Scott (1966) also noted that the cusk eat crabs and molluscs together with an occasional starfish. Our data confirm these observations but add fish as an important potential prey. Bigelow and Schroeder (1953) mention that the cusk is not fastidious as to the bait it will accept, taking clams, cockles, and herring quite readily. The diversity in the prey for the different geographic areas (Table 7) tends to corroborate their observations, that is, the cusk will prey on whatever animals are available.

Red hake.—The dietary information summarized by Bigelow and Schroeder (1953) is generally for both red and white hake combined although they do mention one instance where the bellies of red hake were distended with sand lance, *Ammodytes* sp. In an earlier paper, Linton (1901) reported finding shrimp, amphipods, and the lenses of some small fish in red hake stomachs, and Breder (1922) noted that the one stomach he examined was full of prawns. From the current study (Table 1), red hake has been identified as a mixed feeder, preying on both fish and invertebrates. Crustaceans were the most important prey, followed by fish, molluscs, polychaetes, and echinoderms, in decreasing quantities. Vinogradov (1972) examined the stomachs of 5,486 red hake collected in the northwest Atlantic and, based on frequency of occurrence, found that invertebrates were the most important prey although substantial numbers of fish and squid were also consumed. Vinogradov's study was conducted from 1965 through 1967, and our study from 1969 through 1972. Over these years the major prey of northwest Atlantic red hake appears to have been the same, with any differences observed in the species composition of the diet most likely relating to differences in the sampling sites and local abundance of certain prey.

Spotted hake.—Spotted hake were identified as mixed feeders, relying on both crustaceans and fish as major prey (Table 1), although cephalopods were also somewhat important. Comparative data on the diet of these predators are scanty. Hildebrand and Schroeder (1928) noted mysids in the stomachs of small hake from Chesapeake Bay and Bigelow and Schroeder (1953) only mentioned the food of spotted hake in passing, noting that it fed on fish, squid, and crustaceans. More recently, Sikora et al. (1972) examined the gut contents of 341 juvenile spotted hake and identified crustaceans, especially the macruran mud shrimp, *Upogebia affinis,* as the most important prey, while fish ranked second in the diet. Comparative information on the food of adult spotted hake is completely lacking.

Haddock.—Haddock has a long history of commercial importance and as a result a voluminous amount of dietary information has been collected over the years and the literature on the North American stocks alone is reasonably extensive: Atwood 1866; Verrill 1871, 1873; Baird 1889; Willis 1890; Kendall 1898; Clapp 1912; Needler 1929; Vladykov 1933; Homans and Needler 1944; Bigelow and Schroeder 1953; Wigley 1956; Templeman 1965; Wigley and Theroux 1965; Kohler and Fitzgerald 1969; Tyler 1972.

In one of the earliest papers, Baird (1889) remarked that a complete listing of the prey of haddock would include almost all the fauna of any given area. An examination of the papers listed above gives much credibility to such a statement. It would be impossible to generally classify the haddock's dietary preferences except to say that they usually prey more heavily on benthic invertebrates than fish although they are highly opportunistic and will prey on, for example, fish eggs if they are available. Within one of the geographic areas considered here the diversity in the haddock's diet has been clearly demonstrated by Wigley (1956). He investigated the haddock's food habits on Georges Bank found that the data warranted a division of the bank three different food-type areas.

The results from our study (Table 1) indi ophiuroids were the most important prey and that p chaetes, crustaceans, and fish eggs ranked second importance. The significance of fish eggs in the some interest. Bigelow and Schroeder (1953) stated haddock have been accused of feeding on herring spa but they doubted that this was true. Our obs do, in fact, confirm that haddock will prey gr herring spawn as had also been reported by Bown (1923) and Nikolsky (1963). This type of feeding havior is not uncommon since haddock have found to consume quantities of fish eggs capelin, *Mallotus villosus*, spawn in the Barents (Tseeb 1960) and on the Grand Banks of Newfoundl (Templeman 1965). These results confirm th nature of haddock feeding.

Fourbeard rockling.—According to Bigelow Schroeder (1953) the food habits of the fourbe ling have not been investigated on this side of the At tic. From reports on the stomach contents of British Scandinavian fish they concluded that the fourbeard rockling would probably eat shrimp other small crustaceans, and fish fry. Leim and Sc (1966) commented that much of the biology of fourbeard rockling is unknown since it is rarely commercial trawls because of its small size. suggested that it would eat small crustaceans and but gave no further details. In the study reported her total of 48 stomachs was examined and our obs confirm the suppositions of these previous aut major prey were found to be crustaceans, with the sa shrimp, *Crangon septemspinosa*, being of primary portance (Table 1).

Macrouridae.—There is little information on the fo of either the marlin-spike or the longnose grenad ever, other grenadiers are generalists in thei habits (Pearcy and Ambler 1974; Haedrich and Hend son 1974). We found that crustaceans and polychae were the major prey of the marlin-spike (Table too few fish were collected to make any firm co regarding the feeding habits, our results agree with servations by Hansen (1915) and Bigelow and Schroe (1953).

Ocean pout.—Ocean pout are a bottom fish wh prey heavily on echinoderms and crustaceans (Table Almost three-fourths of their diet consisted of dollar while rock crabs and amphipods accounted for majority of the crustaceans. Olsen and Merriman (19 collected ocean pout in the southwestern part of of Maine and in Southern New England where th tified the sand dollar as the major prey. They report rock crabs and the amphipod, *Unciola*, as being of s ondary importance although some fish had also valve molluscs such as *Yoldia* and *Pecten*. Smit ined the stomach contents of ocean pout collected ock Island Sound, in Southern New England. The prey in this area was the amphipod, *Lep-* *s pinguis,* with the sand dollar being the second important prey. Tunicates were also important, up almost 10% of the diet by weight. In the pres- y tunicates were again found to be a reasonably nt prey item but only in the Gulf of Maine. Bige- and Schroeder (1953) examined the stomachs of out taken in Massachusetts Bay in 1924 and near tucket Lightship in 1950. They found that the arge specimen from Massachusetts Bay was full ttle stars and spider crabs while the animals taken Lightship were full of small sea scallops.

ary Overlap

rcentage similarity in diet (Fig. 3 and text) is a measure of overlap of the food habits, where p is simply defined as the use of the same resource than one predator regardless of the resource ce. In contrast, resource competition exists only demand for prey outstrips the immediate supply herley 1963; Keast 1965, 1977; Zaret and Rand he index of diet overlap presented here, there- highlights the potential for food resource com- n between these fish populations which could exist ain prerequisites were met, as discussed below.

stribution of many of these fish, especially the ially important species, has been documented he groundfish survey data collected by the per- the Woods Hole Laboratory (Colton 1955, 1972; 5; Grosslein and Bowman 1973; Grosslein and 6[3]). The ranges of many of these predators over- wever, the major concentrations of the different f fish are not usually the same. Fritz (1965), for has summarized the distribution of seven om the autumn groundfish survey data, 1955-61. ults showed that silver hake were ubiquitous, but 6-yr study they were most abundant off Cape to the south, and also on the western and south- parts of Georges Bank. Atlantic cod occurred f lat. 41°00′ and were abundant off Nantucket, Cape Cod, and southeast of Nova Scotia. The pollock, and white hake might be considered species as they, like the Atlantic cod, all occurred f lat. 41°00′. The major concentration of haddock e northern edge of Georges Bank and on Browns llock were abundant near Nova Scotia but also d in moderate concentrations in the Gulf of White hake were found along the northeastern eorges Bank and also in the Gulf of Maine. Red urred throughout the area ranging from Nova o Cape May, N.J., being most abundant south of Cape Cod. A more recent summary of the groundfish survey data has been prepared by Grosslein and Clark (see footnote 3). This document includes both spring and autumn cruise data which gives some idea of the seasonal changes in the distribution of the commercially important gadoids. Although certain species, such as red hake, have distinct seasonal migrations, the overall distribution of many of these fish is reasonably constant throughout the year and even from year to year. Colton (1972), for example, found no major change in the general distribution of the haddock during the period 1950-68 despite changing trends in seawater temperature. From this survey data it may tentatively be concluded that, on a broad scale, although some spatial overlap occurs between many of the 15 gadiform fishes we have studied, the major concentrations of each fish are usually sufficiently distinct so that competition between the various populations for the same food resource would be minimal. On a more localized scale, however, spatial overlap may occasionally be severe as has been documented by Grosslein and Bowman (1973). They considered the problem of bycatch in ICNAF Subareas 5 and 6 (Georges Bank to Cape Hatteras), pointing out that a bottom trawl fishery in these areas could not be conducted without harvesting a substantial mixture of species. In particular, aggregates of red and silver hake are consistently found in Southern New England as are mixtures of Atlantic cod, haddock, and hake on Georges Bank. For situations such as these, food habits studies would have to be conducted on fish collected from mixed catches to determine if the fish are feeding on the same prey at the same time or if there is significant resource partitioning, thus eliminating the potential for competition as was found by Jones (1978) for some gadoid fishes in European waters.

Even if spatial overlap were to occur on a significant scale, it may further be counteracted by short-term temporal changes in predator distribution and activity. Daily activity cycles may effectively function to segregate predators although the predators would, at times, share the same prey (Graham 1924; Rae 1967; Brunel 1972; Daan 1973; Arntz 1974; Jenkins and Green 1977).

Finally, even when the spatial and temporal distribution of these species is accounted for, it is difficult to make firm conclusions regarding resource limitation without an extensive knowledge of the benthic community available for exploitation. Studies such as those conducted by Arntz (1971, 1973, 1974) which combine food habits investigations, feeding chronology experiments, and a quantitative evaluation of the macrobenthos are needed before we can quantitatively determine the degree to which food resource competition actually exists.

A number of nonbiological factors may also influence the calculation of dietary overlap and these must be accounted for when interpreting overlap data. The level of identification of the prey will affect the overlap calculations since broader taxonomic groupings actually increase the observed degree of overlap. Moyle (1977) gave an example of this when comparing the diet of sculpins

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and some salmonids, noting that the greatest overlap occurred when the prey was only identified to the order level. In the present study the same effect may be observed. If, for example, the percentage similarity is calculated for the diet of Atlantic cod and silver hake at the highest taxonomic level given in Table 2, the similarity increases from 58% (Fig. 3) to 89%. On the other hand, Keast (1977) justified the use of broader taxonomic groupings for sorting prey; he argued that the body size of the prey rather than finer taxonomic identity is important for studies on fish food habits. It would appear that there exists an optimal level of taxonomic classification for prey identified for dietary overlap calculations. This optimum is probably primarily dependent on the size of the prey, provided the prey shares a similar ecological niche, since size dependent prey selection has been well-documented for fish (Keast 1965; Tyler 1972; Daan 1973; see also Edwards 1976). Apart from the level of taxonomic identification, sample size is probably the second most important nonbiological factor influencing dietary overlap calculations. The smaller the sample the more variable the percentage similarity. This effect was noted in the results for the marlin-spike and longnose grenadier where a relatively small change in sample size, and, consequently, in the quantity of prey consumed, could have a large influence on the observed composition of the diet and any resulting overlap estimates.

Bearing in mind some of the limitations discussed above, an overall pattern emerges from calculating and categorizing the percentage similarity between the fishes' diets (Fig. 3) which is not as readily apparent from a cursory examination of the tables on stomach contents for each of the 15 predators alone. Generally, the greatest block of similarity occurs in the upper left section of Figure 3 while the lowest level of overlap is in the upper right-hand section of the same figure. This reflects two distinct feeding types as revealed by an examination of the data in Table 2. Thus, fish populations such as Atlantic cod, pollock, silver hake, white hake, offshore hake, and cusk are decidedly piscivorous while the haddock, longfin hake, fourbeard rockling, marlin-spike, longnose grenadier, fawn cusk-eel, and ocean pout are characterized more as benthic, invertebrate feeders. Red and spotted hake are intermediate, resulting in a very similar diet which overlaps both the piscivores and benthic invertebrate feeders.

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